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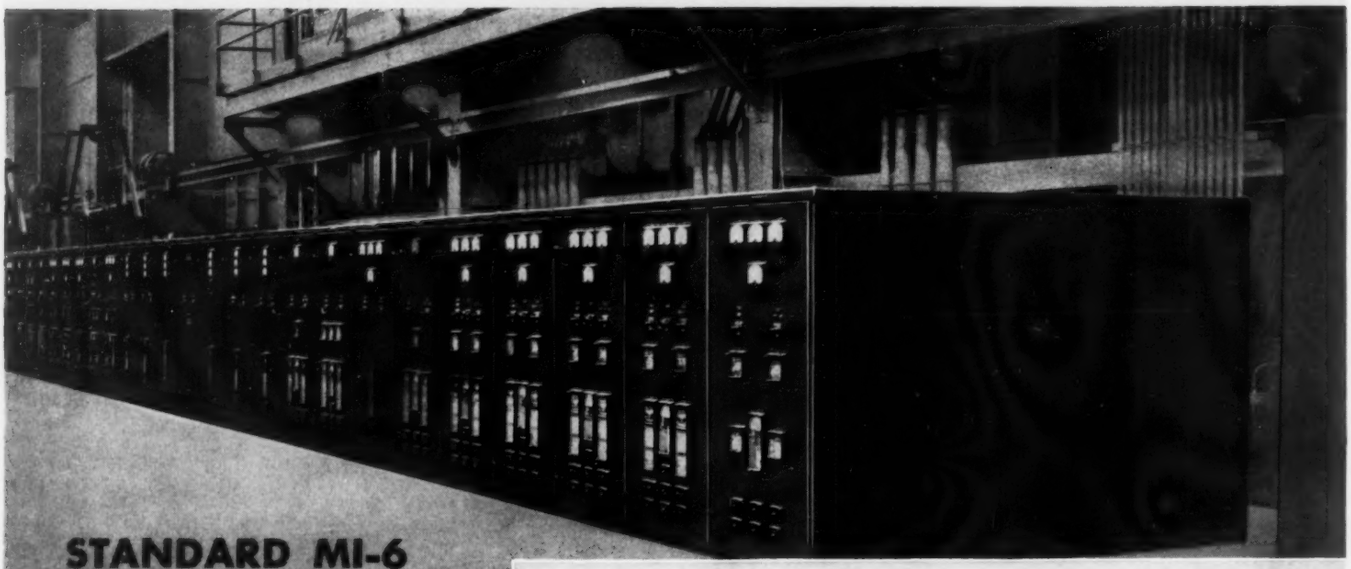

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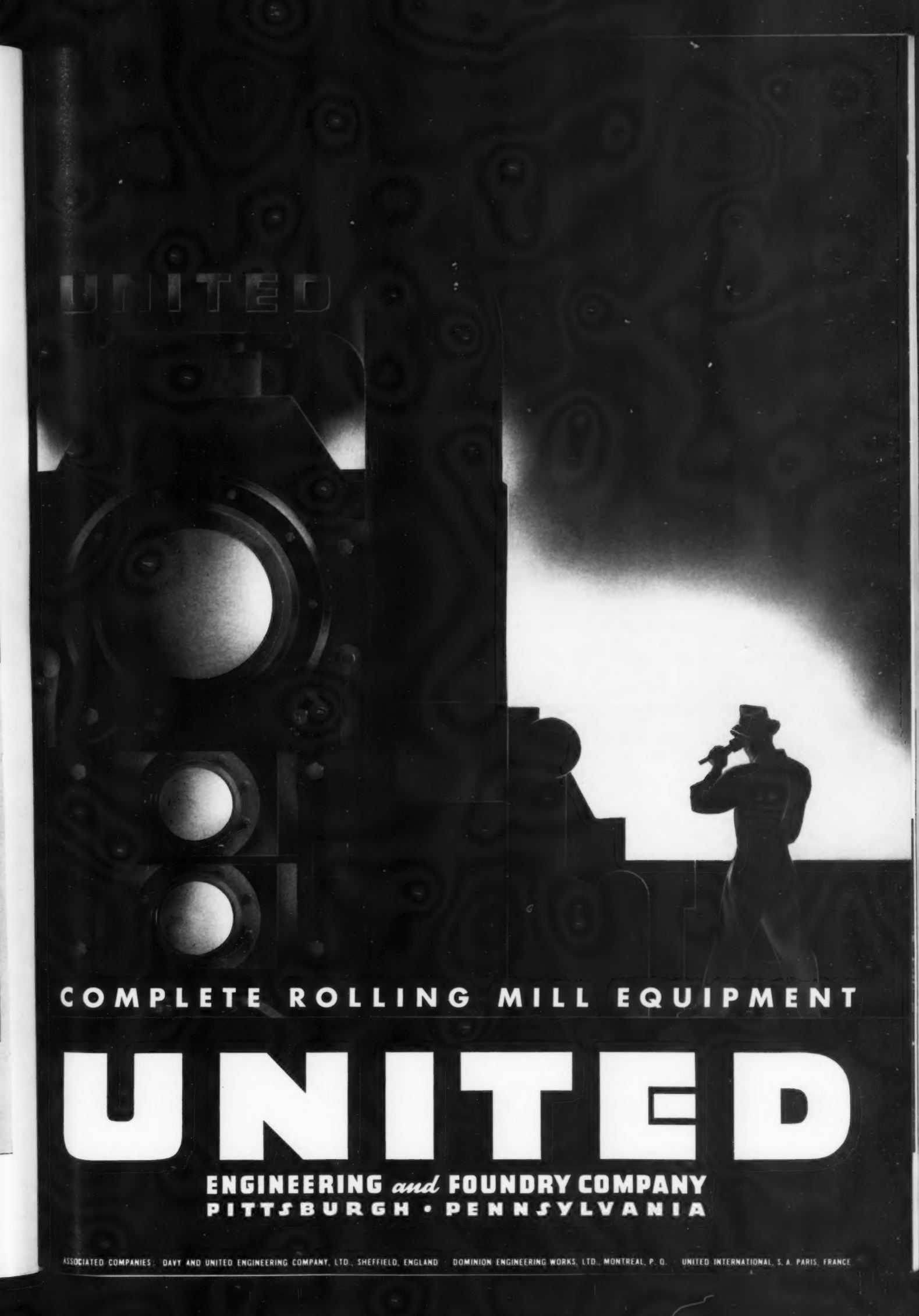

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Electrolytic PICKLING of STRIP Steel

By H. W. NEBLETT

INLAND STEEL COMPANY

▲ THE electrolytic pickling of steel in either strip or sheet form has only been employed in comparatively recent years. The electrolytic action is as old as electricity itself and has been evident in many ways throughout the entire application and use of electricity. One of the very common and familiar, as well as troublesome evidences of this principle is the well known electrolysis action which is present when stray ground current is encountered.

One of the early commercial applications of electrolytic action was employed in the refining of copper and other similar metals. Also, electrolytic action was employed in the plating of metals on surfaces requiring a high finish or protective coating which, of necessity, should be very thin. This application is best evident in nickel plating and chromium plating of automobile parts and similar equipment.

Electrolytic action has been quite generally employed in steel mills and other industries for cleaning steel sheets. For example, the very familiar and almost universally used hot caustic electrolytic scrubber equipment which is used for removing oil and dirt from cold rolled sheets is a very common example of the employment of this principle. It is therefore rather surprising since the principle of electrolytic action has been known so long and has been employed in many commercial ways, to find that it is only in recent years that it has been applied to pickling or the removal of scale from steel in a sulphuric acid bath. The reluctance in making this application has no doubt largely been due to the physical difficulties encountered rather than a lack of appreciation of the benefits derived from such an installation.

EXPERIMENTAL DEVELOPMENT

Approximately five years ago, Inland Steel Company began experimentation with the idea of evolving some feasible manner of employing electrolytic action in conjunction with, and to augment, the pickling of strip steel. This naturally required that the equipment should be applied to the regular continuous pickling lines. The first experiments demonstrated conclusively that the removal of scale from steel could be expedited materially by the use of electrolytic action. Early experiments were made to determine the feasibility of using either direct or alternating current. It was found that practically equally successful results could be obtained from either alternating or direct current. Considerable thought was given to the method of applying the current to the sheet which was being pickled. Theoretically, the logical method would be to apply the current to the strip steel allowing this current to pass from the strip to electrodes suspended in the bath on either side of the strip steel. This would result in the scale being removed from both sides of the strip simultaneously.

In actual practice, it was found quite difficult to apply the current directly to the steel strip. This method would require contact rollers at frequent intervals throughout the length of the tank to equally distribute the current to the steel strip. No current conducting material suitable for making rollers could be found that would stand up in service when subjected to electrolytic action in sulphuric acid. This definitely indicated this method was not feasible. Next considered was the use of top and bottom electrodes, spaced about 18 in. apart, and passing the strip between these electrodes imposing direct current on the top electrodes allowing it to pass through the strip to the bottom electrodes. While this is a workable arrangement, it results in cleaning only one side of the strip and the process would have to be repeated in reverse action in the second tank to accomplish cleaning on both sides of the strip.

Another factor to be considered is the heavy current at low voltage required. This would involve large low voltage direct current generators of high ampere capacity which should be located adjacent to the electrolytic pickling tanks to eliminate long runs of heavy bus bar connections to the electrodes. Suitable space for such equipment is not readily available. Due to these factors it was then decided a more practical method was to employ alternating current which would result in the current flowing in both directions between the electrodes passing through the strip which is located between the electrodes and thereby cleaning both sides of the strip at one time.

Transformers can quite readily be installed in the available space adjacent to the pickling tanks and the current supply can be readily controlled by solenoid operated contactors located at any suitable point in the primary circuit to the transformers.

Considerable research was made to determine the most satisfactory electrode material resulting in the selection of commercially pure rolled lead sheets containing 8 per cent antimony for forming the electrodes.

Iron sulphate has a direct effect on the electrical resistance of the acid bath. With a fresh acid bath containing no iron sulphate the resistance to the flow of current is very little. As the iron sulphate is deposited

H. W. NEBLETT, Development and New Design Engineer, Inland Steel Company, Indiana Harbor, Indiana, presenting his paper before the A. I. & S. E. Annual Convention, Cleveland, Ohio, September 27, 1938.

in the bath the electrical resistance increases proportionately, making it necessary to have a variable voltage in order to obtain the proper flow of current between electrodes at all times. At least 100 amperes per square foot of electrode surface is required to secure proper electrolytic pickling. The current can be varied anywhere from 100 to 150 amperes per square foot and good results will be obtained. With a current density of less than 100 amperes per square foot, the electrolytic action is materially retarded. With a density in excess of 150 amperes per square foot, the action is not appreciably increased.

Current control is obtained by using transformers provided with a series of voltage taps covering a range of 7 volts to 15 volts, 5 taps being provided at 2-volt intervals. This provides voltage variation to insure proper current control at all times, irrespective of the strength of the acid or the iron sulphate content of the bath.

It is advantageous to use short low voltage leads between the transformer and the electrodes. Therefore, it was decided to install two or more transformers adjacent to each tank, thereby cutting down the length of conductor leads to a minimum.

The uniform distribution of current throughout the entire area of the steel to be pickled is important. In order to accomplish this, the electrodes were designed in sections, each section having a width approximately equal to the width of the tank and a length of approximately 6 ft.–6 in. Six electrodes, both top and bottom, were installed in each tank, resulting in approximately 40 ft. of active electrode area in each 60 ft. pickling tank. Due to lead being a rather poor conductor of current, it is desirable to bring the current into each electrode at a multiple number of points. In this case, 4 points for each electrode were decided upon.

DESIGN AND INSTALLATION

The usual continuous pickling line consists of four acid bath tanks in series, each tank being approximately 60 ft. long. Electrolytic action is most pronounced after the sulphuric acid has penetrated the scale and has reached the surface of the steel. We decided to install electrolytic equipment in tanks Nos. 2 and 3 using tank No. 1 as a conditioning tank to allow the acid to penetrate the scale, delivering the steel to the two electrolytic tanks where the major part of the scale is removed. The fourth tank, which is immediately after the electrolytic tanks, is only used as a clean-up tank, as approximately 98 per cent of the scale is removed in the two electrolytic tanks.

The power supply is furnished over a 6600 volt, 3 phase feeder to a bank of 2 single phase transformers located outside the pickling building. These transformers are 750 kw. each, 6600 volts primary, 440 volts secondary, 25 cycles. They are Scott connected to give single phase 440 volts supply to the low voltage transformers located adjacent to the pickling tanks. Two of these transformers are installed at each electrolytic pickling tank, making a total of 4 transformers for the 2 tanks. Each transformer is 225 kva. single phase, 440 volt primary, 15 volts secondary, 25 cycles water cooled. Each transformer is provided with a five point tap changer on the primary side which will give a secondary voltage range from 15 volts down to 7 volts. The secondary of each transformer is made up in 3 segregated windings, each winding connected direct to one top and one bottom electrode. The current supply to the transformer is controlled by means of multiple solenoid operated air brake switches installed in the 440 volt supply circuit. The control for these switches is located on the pickle line operator's control board. They are also automatically controlled through relays in the pickle line drive motor circuits so connected that the electrolytic power is on only during the operation of the lines and automatically shut off each time the line is stopped. This prevents pickling action continuing while the strip is not in motion.

The top electrodes are made up of a cast lead frame in which are embedded two 3 in. x 1 in. copper bars for the distribution of the current. The lead frame is covered over entirely with sheet lead containing 8 per cent antimony and using burned joints. The bottom of the electrode is made of a 1¼ in. thick lead sheet, the remaining surface is covered with sheets ¼ in. thick. Current is brought into the top electrodes at four points through 1½ in. round copper studs which are threaded into the 3 in. x 1 in. copper bars. These studs also act as supports for the electrodes. These copper studs are protected from the action of the acid by means of a wrapping of synthetic elastic tape or glass fabric tape impregnated with a synthetic liquid compound.

The bottom electrodes are made of a flat sheet of

8 per cent antimony rolled lead 1½ in. thick. These electrodes rest on the bottom of the tank flush with the top of the brick lining. At intervals throughout the area of the bottom electrodes, holes are cut which provide for tiers of brick to protrude approximately four inches above the surface of the electrodes. These act as supports for the steel strip and prevent it from coming in contact with the electrodes. Current is supplied to each bottom electrode at 4 points, using copper bars as conductors. The conductors terminate in a solid cast lead terminal which is burned to the bottom of the electrodes. The conductors are covered with a ¼ in lead sheath which in turn is insulated with either synthetic elastic tape or impregnated glass fabric.

The terminals connecting to the top and bottom electrodes carry a heavy current and it is necessary that they be well insulated to prevent current leakage and electrolytic action on the conductors. An insulation material should be provided that will stand up under the action of hot sulphuric acid and acid vapor. Deterioration takes place most rapidly at the acid level. Good grades of rubber will give very acceptable service in acid or vapor with temperatures up to 125 degrees F. The temperature of the acid bath is approximately 190 degrees F. At this temperature the life of rubber is greatly reduced. Rubber was first used for insulation but due to the high temperature encountered, was not entirely satisfactory.

A synthetic elastic was found to stand up remarkably well. We are now using a woven glass fabric tape impregnated and sealed with the synthetic compound. In some cases this tape is applied over the rubber, in others, it is applied directly to the conductor and in both installations has proven entirely satisfactory.

Lead electrodes give very good service and have an operating life of 2½ to 4 years depending upon the thickness of the lead plate used. It has the disadvantage of heavy weight and while deterioration is gradual it is evidenced by the forming of lead sulphate in the tanks. This is not harmful to the steel while in suspension, but does require flushing out of the tanks with high water pressure at frequent intervals to prevent the accumulation of lead sulphate sludge in the bottom of the tank.

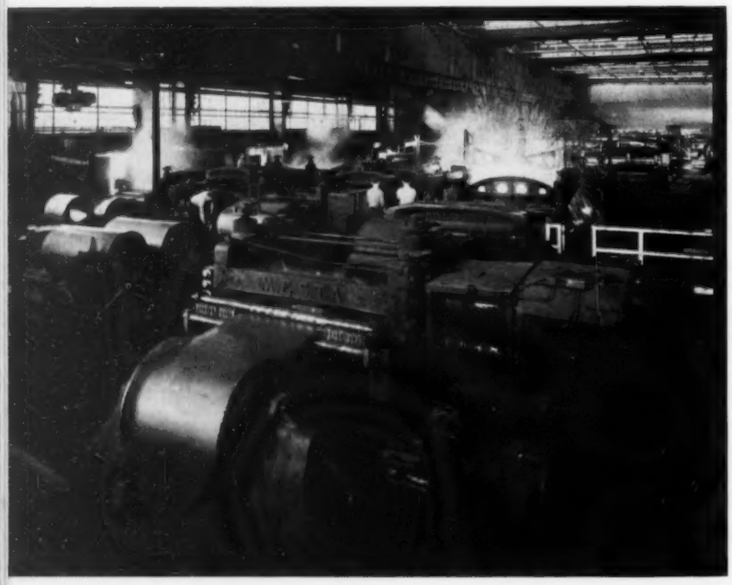
In recent months we have been experimenting with graphite electrodes which are fabricated from graphite slabs into units of the proper size. Electrodes made of this material have the advantage of light weight, the elimination of lead sulphate contamination in the acid bath and practically no deterioration from electrolytic action. While our experience with this material has not been of sufficient duration to be conclusive, the present indications are it will prove a very satisfactory electrode material.

It is necessary to provide some means to prevent the steel sheet from coming in contact with the top electrodes as it travels through the pickling tanks. Various stationary devices were tried out and found unsatisfactory because the sheet would tend to catch on and damage the hold-down devices.

It was decided to install a hold-down roller at each end of the electrodes in each tank. The selection of the proper material for and the design of these rollers required considerable experimentation and research. The rollers are required to operate submerged in the acid and are subjected to the combined effect of hot dilute sulphuric acid, iron sulphate, electrolytic action, mechanical wear and shock. The materials that will stand up almost indefinitely in sulphuric acid, such as bronze and monel metal will be dissipated in a very few hours when subjected to electrolytic action. Bearings have to operate submerged with no lubrication other than that of the hot sulphuric acid. Under these conditions the materials available for satisfactory performance are limited.

A roller assembly has been evolved which stands up well and gives long life and service. This consists of a roller with extended shaft made from a dense and compact compound using a resinous base and asbestos binder. It is fitted with glass bearings. The bearing block and head is moulded of the same material as the roller. The rollers are supported in the tank by steel pipe arms which are covered with rubber over which an outer wrapping of glass fabric tape impregnated with synthetic elastic is applied. This type of roller has given very satisfactory service and has been employed exclusively during the past two years.

Typical installation of pickling units in a cold strip mill showing welding of two coil ends together before entering the continuous pickling tanks.



OPERATION

Our electrolytic pickling equipment has been in operation since the early part of 1934. We have one pickling line so equipped. The installation is made on a line that is used almost exclusively for pickling coils for tin plate. The majority of the coils put through this particular line are narrow and of light gauge resulting in a greater lineal length per ton than is the case with wider and thicker coils. Due to this, a greater speed is required on this line to produce a given tonnage in the same time. The handling of coils at the feed end of the

pickle line, including levelling, shearing and welding, or stitching, requires a given amount of time regardless of length of coil. If the coils are long, as is the case in this line, the time required for handling is proportionately less comparative to the total time required for the entire coil to pass through the pickling bath than is the case on shorter coils. This provides considerable leeway between the time consumed in entering and preparing the coil for passing through the pickling lines and the total time required to pickle a coil. Under these conditions, if the pickling speed can be increased, by any means, a greater tonnage will be realized from a continuous pickling line. This is the reason for our installing electrolytic pickling on this particular line. This is an important point to be borne in mind wherever an increase in pickling speed is under consideration. For example, assume a pickling speed of 80 ft. per min. and a coil length of only 160 ft., it will require two minutes for the entire coil to pass through the pickle bath. If two minutes are also required to place a new coil in the feed reel, feed into the leveller, shear, weld and trim, the time of the two operations balances and any increase in pickling speed would result in the pickling line having to be stopped until the feed end is ready with a new coil. Therefore, no gain in tonnage would result from any increase in the pickling speed. On the other hand, assume a pickling speed of 80 ft. per min. and a coil length of 240 ft. Under this condition, it will require three minutes for the coil to pass through the pickle bath. If two minutes are required to place a new coil in the feed reel, feed into the leveller, shear, weld and trim, one minute of time remains before the entire coil will pass through the pickle bath. Under this condition, any increase in speed of the strip through the pickle bath will result in an increase of tonnage produced on the lines and the pickling speed could be increased to 120 ft. per min. and still coincide with the feeding time of two minutes for the coil.

The coils pickled on our electrolytic pickling line range in length from 300 ft. to 360 ft. The time required to handle the coil at the feed end including shearing, welding and trimming is 1½ minutes average with a maximum time of two minutes. This provides for a strip speed through the pickle bath of at least 150 ft. per min. Before electrolytic pickling was installed on our line, the strip speed was from 70 to 90 ft. per min. After the electrolytic equipment was installed, the strip speed through the pickle bath is from 120 to 170 ft. per min., with occasional speeds, under ideal conditions, of 200 ft. per min. This wide range of pickling speeds is due to a number of factors such as coiling the steel hot, or somewhat cooled before coiling in the hot mill, coils stacked hot and allowed to cool before pickling or feeding into the pickler while steel is fairly hot, high phosphorus or high carbon steel coils, all pickling tanks full of fresh acid of 10 per cent H_2SO_4, or part or all of the tanks with low acid and high iron sulphate content. Any one of these factors has a direct effect on the speed of pickling and when a combination of tight scale, low phosphorus and low carbon steel, weak acid and high iron sulphate content in all tanks is encountered, the lowest pickling speed is the result.

In practice, we find that the acid in tanks Nos. 2 and 3, due to the majority of the scale being removed in these tanks is used up most rapidly. In normal operations it is necessary to dump and refill these two tanks every 48 hours. Tank No. 1 has a life of about 72 hours, while tank No. 4 will last from two to three weeks. We maintain the acid content of our tanks at 10 per cent H_2SO_4 by periodically adding acid. In the case of tanks Nos. 2 and 3, the electrolytic action in these tanks maintains the temperature at 190 degrees F. at all times during operation. No steam jet heating is used as is the case on tanks Nos. 1 and 4. Due to this, it is necessary to add water at intervals to tanks Nos. 2 and 3 to maintain the proper acid solution. When the iron sulphate content of the tank reaches 25 degrees Baume, the contents are ready to be dumped. We then raise the temperature to 200 degrees F., no acid is added, and when the remaining acid is used up, the Baume of the tank will reach approximately 32 degrees. At this point the tank is dumped, cleaned and a new acid bath installed. During the period that the acid is being reduced and the iron sulphate content increased, the resistance of the acid bath is increased. This necessitates the voltage on the electrodes being increased to maintain a constant flow of current of at least 100 amperes per sq. ft. of electrode area. This is accomplished by means of the secondary transformer taps previously mentioned.

Any increase in speed of pickling due to electrolytic action, over what can be obtained without it, results in a direct increase of tonnage from the pickling line. This tonnage is realized with no increase in labor or overhead. The only additional cost of this additional tonnage of pickled steel is the interest on investment of the electrolytic equipment, its maintenance and the cost of the current consumed. These costs should be charged entirely to the additional tonnage realized. We obtain an average increase of 35 per cent in tonnage with the electrolytic over what would be obtained on the pickling line without electrolytic. The electric load

Continuous pickler installation showing the hot rolled coils as they start through the pickling units.

of the electrolytic equipment is 600 kw. The interest on investment, the maintenance and the costs of the current consumed are equal to 46 cents per ton on that part of the tonnage that results from the use of electrolytic equipment. This is quite an attractive saving when compared to normal pickling costs without electrolytic equipment. In addition to the increased production realized, there is a saving in the heating of the acid bath in the electrolytic tanks as the current will provide sufficient heat to maintain the bath at proper temperature during operations.

An electrolytic installation will increase the speed of pickling on any pickling line regardless of the type of scale, the amount of scale breaking equipment used or the grade of steel being pickled. To realize the full advantage of this increase in speed and to actually secure an increase in tonnage, the pickling line, as a unit, must be able to operate in the time required for a coil to pass through the pickle bath. Under this condition an electrolytic installation will show a very good return on the investment. If this condition does not exist, the time saved by the use of electrolytic equipment will be offset by the delays due to preparing a new coil for feeding into the pickling line. In considering the installation of electrolytic equipment, the operation of the entire pickling line equipment must be thoroughly checked to determine if the handling and feeding in of the coil can be done in the time required for the coil to be pickled at the higher speed.

The handling and feeding of coils into pickling lines is consistently being speeded up. More efficient coil handling and processing equipment is being built by the equipment manufacturers. The time required to weld and trim coils is being steadily decreased. All of which results in a cutting down of the time required to deliver a coil to the pickling tanks. This creates a condition receptive to the use of electrolytic pickling equipment which is a definite means of securing increased production from a pickling line.

DISCUSSION

PRESENTED BY

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N. J. RANNEY, Research Engineer, Wean Engineering Company, Inc., Warren, Ohio.

R. M. BAYLE, Engineer, Westinghouse Electric and Manufacturing Company, Chicago, Illinois.

H. W. HOOKER, JR., Hooker Electrochemical Company, Niagara Falls, New York.

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H. W. NEBLETT, Development and New Design Engineer, Inland Steel Company, East Chicago, Indiana.

C. E. BROWN: This paper has a very significant effect upon our understanding of processing conditions today. We have made a great many improvements in our systems of rolling, our systems of finishing, in almost every treatment we are concerned with in the mills, but we haven't made a great many improvements in our fundamental pickling practice.

In the beginning, we all started pretty much at the same place. I know that we have all covered a great deal of the ground work. Some probably has been more outstanding than others. But the development and the successful performance in an operation of this sort is very well timed to the urgent need which we have in this particular process today, and I am certain Mr. Neblett has given us a clear understanding of the operation, about which we are all interested and of the improvements which they were able to effect.

I don't believe that we have realized, in the introduction of an a-c. system of pickling, that we have departed from what we understood normally to be the established practice—that we would be obliged to use direct current, and there is no doubt but that the successful use of a-c. will spread to other operations, such as possibly electrolytic cleaning and effect a material saving in operating cost. Also there is some further benefit in the alternating current system as against direct current.

Possibly the greatest importance of the operation itself is the gain in tonnage. We have a gain in quality and a means of preventing the overpickling of the product. It has provided a more uniform surface, and the question of gain in the prime quality appears to be pretty much settled, from the results mentioned.

The only doubt about the use of the operation is the fact that there may be some question as to the use of lead electrodes. Inasmuch as this pickling line has been pretty well limited to the use of tin plate and production allied with it, there may be some question of the advisability of using lead electrodes. Some years ago—and I believe the project is still active—a company brought out a system of plating and descaling which was a combined operation. The possibility has occurred that there may be some question as to the use of lead, although apparently up to this time there has been nothing detrimental brought out in practice.

The problem of pickling for tin plate processing has always been one of major consideration in the quality of tin plate, both as to the matter ofover-pickling and under-pickling. The performance of electrolytic

pickling will without doubt provide a decreased percentage of pickle salts on the surface of the sheet, and in addition to that should provide a more uniform surface, which will give better metal coating properties.

As far as the time element in splicing coils is concerned and the matter of limiting the pickling to the time permissible for welding, I don't think that is as much a feature as it was some time back because of the greater coil length, and I don't think we are going to approach very soon, with the extreme lengths we have, the minimum time that is required for welding or stitching, a minute and a half, or even two or three minutes.

I think probably the greatest problem of the whole operation is the providing of a durable electrode system and the method of control of the electrical equipment, as has been indicated.

N. J. RANNEY: This subject, as a whole, has been, and still is, a controversial one, and, for the benefit of the art and the industry, it is to be hoped that Mr. Neblett and his company will continue to improve their installation, with a view of reaching the ultimate advantages to be derived for a minimum expenditure.

Certainly, no one can deny the fact that the output of a continuous pickling line can be increased through the medium of electrolytic pickling, and the controversial phase can only be as to whether the cost of securing the increased production by the means of electrolytic equipment warrants the investment.

Mr. Neblett's paper shows a very careful consideration of the technical and operating factors involved, and we concur in his opinion that alternating current should be used in preference to direct current, as this solves many practical difficulties. The necessity for contacting the strip is eliminated. Both sides of the strip are subjected to electrolytic action at the same time, and low voltage transformers are substituted for elaborate motor generator equipment.

The range of current densities selected at Inland, and the percentage increase in tonnage attributed to electrolytic pickling, are reasonably well in line with contemporary experience. However, it is to be noted that the operating speed of the line when used for chemical reaction only was 70 to 90 feet per minute, and this falls considerably below the results obtained on recent installations of continuous picklers with an equivalent tank length. It is to be noted further that even with the electrolytic facilities, the speed range was from 120 to 170 feet per minute, with occasional speeds, under ideal conditions, up to 200 feet per minute. This would bear out Mr. Neblett's statement that speed through pickle lines depends a great deal upon the correlating equipment, permitting fast coil entry and constant flow of material through the pickle lines. On recent installations having equivalent tank length and using chemical reaction only, without any addition such as electrolytic action or other scale removal facilities, speeds ranging as high as 240 feet per minute have been attained, but, again, as Mr. Neblett has pointed out, a partial explanation of this can be found in the composition of the scale present on the steel when coming from the hot mill.

Since high speeds are dependent upon the correlating equipment, and normal speeds of 180 to 200 feet per minute are normal practice, to some extent we have arrived at an opinion that, with such high speeds already available, maximum additional increase in speed from an electrolytic installation cannot be utilized, due to other delays. However, we are continuing to give the subject of electrolytic action and its advantages our study and attention.

It might be interesting to advance here a theory of the action of alternating current in scale removal. Tests indicate that the efficiency of alternating current in increasing the rate of scale removal varies with the chemical characteristics of the bath, the electrolytic action operating to best advantage in a pickle bath of good chemical efficiency. Therefore, the effect of the current seems to be chiefly indirect rather than direct.

An explanation of this is found in the composition of the scale, which consists of an inner bonding layer of ferrous oxide, which is soluble in pickling acid, and an outer layer of so-called magnetic iron oxide, which is relatively insoluble. It would seem that by undermining and loosening the scale by the electrolytic solution of the base metal and by the blasting action of hydrogen evolution, the current contributes a mechanical effect and, at the same time, allows the pickle solution to readily attack the inner ferrous oxide or bonding layer of scale.

Referring again to Mr. Neblett's paper, we notice that the current is automatically turned off on the electrolytic units instantaneously with any stoppage of the strip in the tanks.

At this point, I wish to say that some of the older continuous strip pickling installations are installed in a manner that does not permit continuous operation, but requires the starting and stopping of the strip to shear out a stitch or weld. This may account for a large amount of the difference in speed referred to in Mr. Neblett's paper, and the high speeds being obtained on more recent installations.

It should be a fundamental rule, both from the standpoint of tonnage as well as quality, that the strip should never stop in the pickle tanks. Naturally, such perfection cannot be attained, for, under the most ideal conditions, there will be delay, but the nearest approach to perfection that can be made is the best insurance for maximum production and uniform quality of pickling, and every step taken to insure a constant, uniform flow of material through the tanks is most certainly a step in the right direction.

Some of the steps taken to accomplish this in more recent installations have been such things as the coil cradle car for delivering coils to the processing uncoiler for fast coil entry, the use of large coils, made either direct from the mill or built up by welding, improved guiding equipment, proper location of control pulpits, mechanical facilities for eliminating all hand labor, ample and properly located looping pits, and quick ejecting means for removing the finished coil at the exit end.

When it is remembered that, in five years' time, production through continuous pickle lines has been doubled in equivalent length tanks, and cost cut in half, it seems that a great deal of progress has been made, but we quite agree with Mr. Neblett that addi-

tional progress can be accomplished by further study of the problem.

R. M. BAYLE: In this excellent paper Mr. Neblett has confined himself entirely to the mechanical aspects of electrolytic pickling. He has agreed with me that you gentlemen might be interested in a brief review of the electrical equipment required to handle this pickling line.

I would first like to call attention to two photographs that were taken of this pickling line before the electrolytic equipment was added. Figure 1 shows the pickling tank looking in direction opposite to strip movement. At the time this view was taken only two lines were installed. The mechanical arrangement of the tanks will give you some idea of the difficulties encountered in placing electrodes in two of these tanks and arranging bus work from adjacent low voltage transformers to transmit a maximum of around 30,000 amperes per tank.

Figure 2 shows the general arrangement of the heavy duty magnetic control equipment used on the various motors propelling the strip through the tanks together with its associated stitchers, shears, etc. At the start of this development the Inland Steel Company made a very wise decision, namely that the magnetic control equipment should not be installed within the confines of the pickling room itself. This decision proved to be a very wise investment and I believe the Inland engineers will bear me out in stating that the maintenance problem has been greatly minimized thereby. The basement of a combination office and service building paralleling the main pickling building was chosen as a location for the magnetic control for this line. Ample space is available for all the present modifications and a very flexible system of duct work is provided for conducting incoming power and control wiring to the various panels. An interesting side light comes to mind concerning the first installation of two pickling lines. On this particular installation 60,000 feet of control wire alone were used.

The first installation consisted of two lines only using mechanical stitchers for connecting the coils together. The total connected horsepower per line was 420.

The next stage in the development of the pickling lines consisted of adding a third line capable of handling somewhat wider strip.

Next the electrolytic pickling equipment was added to line No. 1. The main power supply for the electrodes is secured from a 1500 kva. transformer bank with primaries of 6600 volt, 3 phase, 25 cycles and secondaries of 440 volts, 2-phase, 25 cycles. It may cause some speculation in your minds as to why 2-phase was used on the secondary side of these Scott connected transformers. As arranged the Inland Steel Company desires to equip two tanks only with electrolytic equipment. As the strip passes from tank to tank this meant that the strip itself would create a floating neutral if a polyphase system were used. It seemed impractical to try and place the entire load on a single phase and by using a 2-phase system we were able to balance the load on the 3-phase system. The two phases are electrically isolated and the strip therefore serves as a high resistance neutral tending to establish a quarter phase system with the centers of both phases tied together. This keeps the voltage stress between insulated parts of the tank system at a minimum. As Mr. Neblett has explained particular care is taken that the strip never touches either the top or bottom electrodes so there is never an actual electrical connection and no current passes along the strip.

FIGURE 1—View of two pickling lines from the exit end, showing spacing into which electrolytic equipment was fitted.

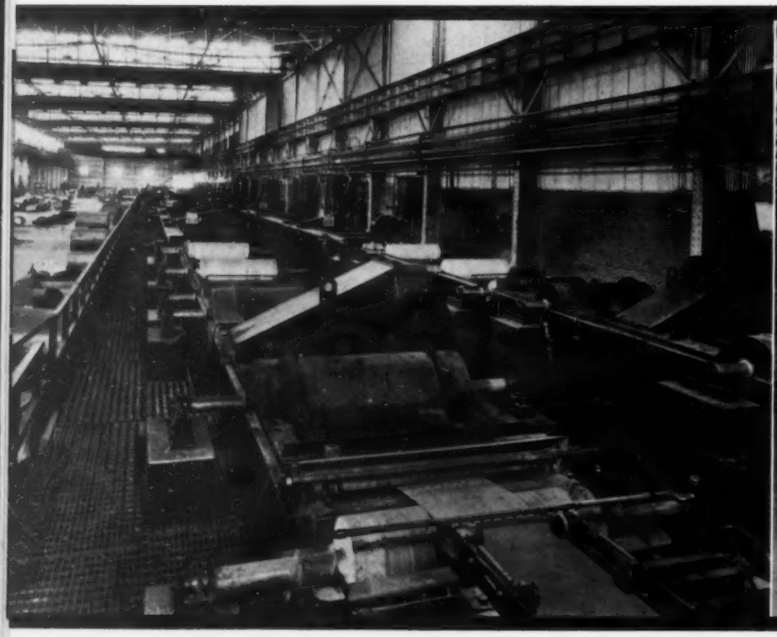


FIGURE 2—The heavy duty magnetic control equipment used on the pickling line drives is placed in the basement of a nearby office building.

The tanks themselves are supplied with low voltage current from 225 kva. single phase transformers. Two transformers per tank are used. The primaries of these transformers are rated at 440 volt, 25 cycles and the secondaries are comprised of three separate circuits each rated 15 volts maximum. A primary tap changer is available in each unit capable of reducing the secondary voltage to 7 volts. Taps for 7, 9, 11, 13 and 15 volts are available. With these tap changers it is possible to select a secondary voltage which will match the particular strip being pickled. In actual experience these taps are not changed very often.

The problem of conducting this low voltage and heavy current into the tank electrodes presented a very neat engineering problem. The ideal arrangement would have been to place one transformer on either side of the tank, but space limitations compelled their installation on the same side. The final design consisted of a complete shop fabricated low impedance bus system manufactured from standard aluminum channel sections. The branch circuits were fabricated from 4 inch channels and a few of the major trunks were made from 6 inch sections. To reduce the reactance to the lowest possible value a special insulated clamp was used which spaced the opposite polarities very close together. The channels were arranged back to back where their mutual inductance was at the lowest possible value. Tests after installation showed a very even current distribution and a very moderate voltage drop. At the points where flexibility was desired due to the raising and lowering of the top electrodes laminated strip aluminum was used.

The third development in these continuous electrolytic pickling lines consisted of adding electric flash welders and their associated equipment. By means of these welders the strip is joined in a single continuous ribbon and larger sized coils are delivered to the cold roll mills consisting of two to three of the original hot rolled coils. With the original equipment it was necessary to cut out the stitch and the hot rolled coil alone was the unit which could be processed in the cold roll mill. The completed weld can be passed through the cold roll mill with no trouble.

This third and last addition requires an additional horsepower of 250, plus a 1400 kw. welder for two of the lines and a 1000 kw. line welder for the other line.

An interesting side light is the fact that the power for these heavy duty welders is taken from the 2-phase 440 volt, 25 cycle distribution system for the electrolytic pickling lines. All three welders are fed from one phase of this 2-phase system and an ingenious interlocking control circuit is used whereby only one welder may be used at a time. To secure a good quality weld it is necessary to keep the supply voltage to the welding transformer fairly stable. The starting and stopping of the electrolytic power does not produce enough voltage change to affect the weld of an adjacent line. While the supply transformers could probably take care of two welders simultaneously, the interlocking system is arranged to permit one only on account of the voltage disturbances of the second one coming on the line. The initial inrush to one of the larger welders is about 1000 kw. which drops to about 600 kw. during the major portion of the weld. The entire welding operation takes approximately 14 seconds.

All in all the writer believes the continuous development of these pickling lines represents an ideal illustration of the flexibility and ease with which modern processing machinery can be handled with specially coordinated magnetic control.

H. W. HOOKER: Mr. Neblett's paper brings out so clearly the factors to be considered in electrolytic acid pickling that it may be appropriate at this point to mention an electrolytic alkali method of simultaneously pickling and cleaning steel which, while it has several features in common with the acid method, has none of the disadvantages connected with handling acid and acid baths. It might be well to point out very briefly the features which this new process has in common with electrolytic acid pickling as well as those which distinguish it from known methods of cleaning steel.

We were struck first by the current densities which the author finds to be best—between 100 and 150 amperes per square foot. Approximately the same current density is used in the alkali method but the overall power cost is somewhat lower with the alkali method due to the lower voltage at which the alkali can be electrolyzed. Linear velocity of the work through the bath as well as the time required for treatment are of the same general order in both processes. In both cases the work is normally made one of the electrodes.

The electrolytic alkali method mentioned is known as the nascent sodium metal cleaning process and it has been in commercial use for a number of years in several metal cleaning applications. The process employs d-c. current, the steel normally being used as cathode in the electrolysis of fused sodium hydroxide (caustic soda) to produce at the steel surface a very powerful deoxidizing agent—namely nascent sodium. The sodium, although electrolytically produced, effects a straight chemical reduction of any oxides on the steel surface, carrying the oxygen of the scale off as sodium oxide and leaving reduced iron which falls off the metal in the bath or is easily washed or brushed off after the work leaves the bath. The anode products in this electrolysis are oxygen and water and the oxygen rises to the surface of the bath at the anode, bubbling into the air. The water diffuses through the molten bath and combines with the aforementioned sodium oxide produced at the steel (or cathode) surface to re-form sodium hydroxide so that the fused caustic electrolyte is constantly regenerated and the oxygen of the scale is transferred to the anode and discharged to the air leaving reduced iron which falls to the bottom of the tank or is later washed off as the case may be. In theory it would appear that the only cost of procuring this result should be the power used to supply the current but in practice it develops that a small amount of caustic soda is dragged out of the bath by the metal upon its removal from the tank. This carry-over is normally washed off the steel, along with any reduced iron which may be carried out, in a water bath following the caustic cleaning bath and it can easily be recovered by evaporation if desired and recharged into the fused bath.

It is interesting to note how a combination of electrolytic and chemical reactions such as this can be

used to greatly speed up the operation of cleaning the metal which is our objective. The production of sodium is, of course, instantaneous as soon as the current hits the metal. The chemical reduction of the iron oxide is very rapid but a given amount of oxygen in the scale will require a chemically equivalent amount of sodium to effect a complete deoxidation at the metal surface. Since the amount of sodium produced, as with the deposition of all metals, is dependent upon the current passed and the time, we must continue the electrolysis for a sufficient time to produce enough sodium to combine with all the oxygen present in the scale. With all normal hot rolling and heat treating scales it is found that if a current density of 100-150 amperes per square foot is maintained on the metal surface for a period of one minute there will be sufficient sodium produced to effect complete cleaning of the metal. When the amount of scale to be reduced is small the action will be correspondingly faster —on scale-broken patented wire rod the process is now doing an unusually good cleaning job in twenty seconds or less in a continuous operation, and on No. 10 gauge caustic annealed wire this bath has effected a complete cleaning operation when the wire was run through a 20 foot fused caustic tank at speeds up to 200 feet per minute. The character of the scale appears to make no difference in the speed or efficacy of the process; for this reason the non-ferrous oxides and those of the stainless steels are reduced as rapidly and effectively as those occuring on ordinary carbon steel.

This new electrolytic method of cleaning steel has a number of advantages over the acid methods, both electrolytic and non-electrolytic, now in general use. For instance it is never necessary to dump or change the cleaning bath. Since the caustic electrolyte is self-regenerative it does not become vitiated or deteriorated in any way. It is only necessary to periodically add to the bath an amount of caustic equivalent to that which has been dragged out on the steel surfaces immersed therein. An important advantage lies in the fact that the only effluent from this operation, e.g. the wash water, can be run into any water drain or stream without harm thus eliminating the problem of waste acid disposal which is becoming very serious in some localities today. If desirable this wash water may be evaporated and the caustic recovered, thus eliminating any waste disposal problem. No fumes attend the operation of this process and there is no attack on the surrounding buildings or equipment. This makes for greatly improved operating and labor conditions. An additional and important advantage lies in the condition of the metal after caustic cleaning. Since there is no hydrogen evolved in the reactions producing the result there can be no absorption of this objectionable element in the steel. The resulting surface is therefore in much better condition for drawing or rolling than on its emergence from an acid bath. There is no need of neutralizing or baking the steel prior to further processing so that these two operations can be dispensed with. Since the sodium, which is our cleaning agent, will not enter into any reaction with other pure metals, the deoxidizing action is stopped as soon as all the impurities are removed from the metallic surface and any danger of pitting or over-pickling is eliminated. The temperature of the fused bath (900 degrees F.) is such that all organic or combustible matter is burned off the steel immediately upon its immersion in the caustic so that degreasing (often a separate operation in itself) becomes automatically a part of this one operation. The fused caustic bath can be used at higher temperatures as a heat treating medium with excellent heat transferring properties. This has been shown experimentally and commercially in the annealing of continuous wire in caustic tanks. This means that both heat treating and cleaning may be accomplished in one operation at a very substantial saving in some cases. The speed of the caustic cleaning operation makes it adaptable to continuous operations in situations where the previous acid baths were too slow to allow an efficient continuous unit. No special tanks or equipment are required for installations of the process so that its initial cost is low; also the depreciation of the equipment through use is very much lower than equipment used in connection with acid operations.

The principal features of this new process are as follows:

1. It speeds up metal cleaning and deoxidizing operations greatly.
2. The power consumption used to operate it is very low.
3. Its speed makes it adaptable to continuous operation.
4. It eliminates the waste acid disposal problem.
5. Investment cost is low and equipment does not deteriorate rapidly.
6. Better operating conditions are obtained—also lower labor costs.
7. It is equally effective on all types of scale; stainless, non-ferrous, etc.
8. It produces an improved product—much lighter in appearance.
9. It can be used to combine heat treating and cleaning in one operation.

R. R. THOMAS: I would like to ask Mr. Neblett to tell us in his closing remarks whether or not there is any decrease in acid consumption in pounds of acid per ton of steel, as compared to the usual type of pickling.

Also, is the bottom of the electrode perforated to allow the sludge deposit to pass through?

H. W. NEBLETT: Answering Mr. Thomas' question as to the decrease in acid, our records show there is a small saving in acid. I do not believe this is entirely true. There is a saving, but it comes about in the following way. With the electrolytic the entire amount of heat required is obtained from the electrolytic action. Therefore, no steam is admitted to the tanks. The steam dilutes the electrolyte with water and if you have a tank full up to the overflow and you continue to add more to it, you will naturally have some acid which is wasted. This is what makes up the difference. There is really no saving in the acid from the operating standpoint but there is from actual practice due to this condition.

Referring to perforations in the electrodes, there are no perforations in the bottom electrodes as now in-

(*Please turn to page 30*)

Steel PLANT *Fuel* ACCOUNTING

H. V. FLAGG, Combustion Engineer

AMERICAN ROLLING MILL COMPANY

MIDDLETOWN, OHIO

Presented before the A. I. & S. E. Thirty-fourth Annual Convention, Cleveland, Ohio, September 27, 28, 29, 30, 1938

▲ PRESENTATION of a paper on the rather imposing subject assigned to me is attempted with some trepidation for there is some question whether a discussion of the system worked out for one plant, or even a group of plants, can have enough interest for fuel engineers in general to justify the time required for preparation and presentation. However, it is true that certain problems are common to all plants and this paper is presented in the hope that at least some may glean an idea or a suggestion which may be helpful in their own work or that some contribution may be made towards a standardization of fuel data reporting which may lead towards better understanding and better comparison of fuel performance between various plants.

Mr. Flagg giving his paper a final check, prior to presenting it to the A. I. & S. E. membership.

A word concerning the justification for thorough fuel accounting is in order. From the standpoint of cost alone, good and sufficient reason can be advanced for giving the question of the amount of fuel used the most careful consideration. The cost of fuel per ton of product in a fully integrated steel plant, which includes the blast furnace plant, may run close to five dollars, and it takes but a moment's thought to get some idea of the total amount of money involved in the monthly fuel bill. Common sense tells us that such expenditure calls for exhaustively detailed control. Another and usually more important reason for good fuel accounting lies in the influence fuel utilization has on production and quality. This factor is sometimes lost sight of in the push for low fuel cost, so that a situation may arise where an accomplished fuel saving may be lost many times over in adverse effect on production, quality, or both. The value of good fuel accounting in this connection lies in the fact that no positive knowledge of fuel utilization is possible without accurate, dependable information as to performance. Still another justification for good fuel accounting lies in the necessity for improving poor operations and holding good operations up to standard, which can be possible only if information as to performance is readily available.

In this latter connection, it is timely to point out that good fuel accounting makes it practicable to set up standards which will serve as "bogies" to strive for in the interest of better fuel utilization, and also take into account and make allowance for conditions which affect fuel utilization but are beyond the control of operating personnel.

We propose to discuss our system of fuel accounting in order as follows:

1. Manner of keeping fuel records.

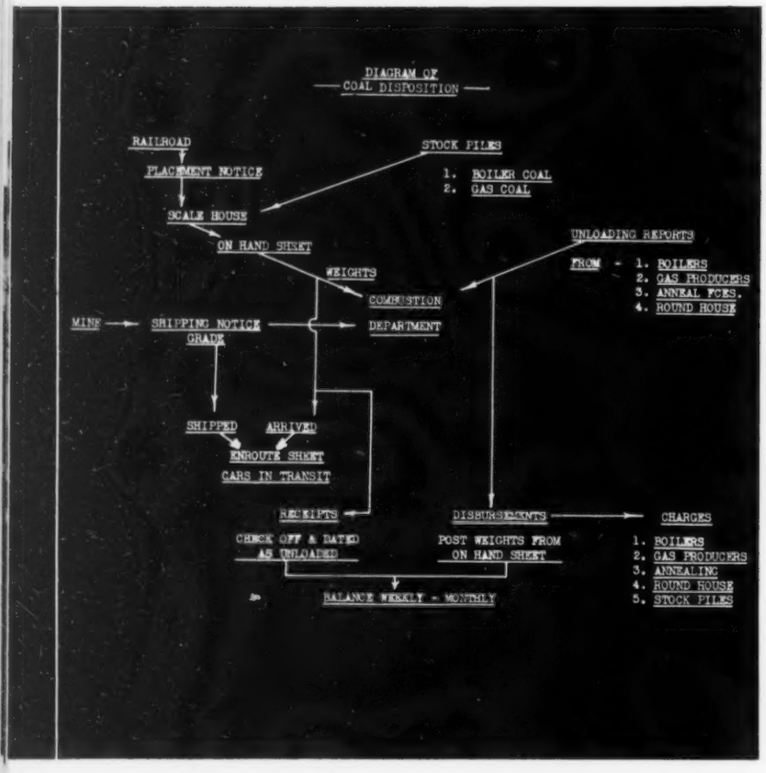
2. Basis on which fuel data is recorded.
3. Control of fuel supplies.
4. Metering set-up used for establishing consumptions.
5. Description of reports issued.
6. Discussion of the set-up of standards in use.

RECORDS

We collect our meter registrations and coal consumptions daily, and keep our records in such a manner that a balance may be struck and complete distribution be made each day. Records are cumulative so that at the end of the month, distribution can be made up for the accounting department by simply posting the cumulative figure for the last day of the period. There are many advantages in making daily records. Most important, the data is accurate since the principle of striking balances minimizes the danger of errors which might go undiscovered until chance of correction is past. Accounting data is available immediately so that cost figures can be out promptly enough to be of real value. If a system of "bogies" is set up to serve as operating standards, and their application is made daily in combination with actual consumption records, it becomes practicable to establish daily cost control which will show at once whether various operations are maintaining their operating standards. At least part of the work involved has to be done daily in any event and the benefits received more than justify the additional work necessary to carry out the complete program.

While the work of keeping such fuel records is entirely routine, it furnishes a very good training ground for young technical men since it takes them into all parts of the plant every day and enables them to get a broader idea of plant operation than is possible on most departmental assignments. Our own experience is that turn-over on this job is unusually large. We have had men move on from this work to departmental jobs, sales, metallurgical department, research work, sales development, foreign assignments, as well as to fuel engineer's jobs in other plants.

Diagrammatic chart showing the routine records of coal receipts and distribution, giving a complete running check on consumption and stock.



BASIS ON WHICH RECORDS ARE KEPT

In plants which use one fuel only and have no interest in making comparisons with other plants, the choice of units to be used for expressing fuel consumption is relatively unimportant. Cubic feet of gas, gallons of oil, pounds of coal, or millions of Btu. all serve equally well to show the amount of fuel used; however, plants using a variety of fuels gain several advantages by reducing all their fuel consumptions to a common denominator. In a plant using producer gas predominantly, for instance, it is practicable to express all fuels in terms of pounds of coal. However, since all such conversions must be made through the medium of heat units, it seems sensible to adopt heat units as the common denominator and since the usual steel mill heat unit is the Btu., the logical unit for expressing fuel consumption is an MM Btu. (thousand thousand, or million, British thermal units). And, since it has to be written so many times and takes up so much space, it may well be written just so—MM Btu.

It is common knowledge that merely reducing the various fuels to MM Btu. does not result in a measure of their comparative value. Such factors as the hydrogen content of the fuel, which must be burned to water with its double loss in sensible heat and latent heat of evaporation, inert content with its sensible heat loss, flame propagation speed, and flame emmissivity rate, all have their effect on the comparative performance of that fuel. Since these factors all vary with different applications, any attempt to bring them all under exact control becomes an endless and well-nigh hopeless task. A compromise which has worked fairly successfully, is to credit the fixed natural and coke oven gases and fuel oil, with their net heating value, defined as total heat value less the heat of evaporation of that amount of water resulting from combustion. Coal, as producer gas, is credited with a percentage of the total coal heating value corresponding to the efficiency of good producer operation, and raw coal with a percentage of total coal heating value which makes allowance for the losses incident to the amount of excess air necessary for good combustion and to the amount of combustible lost in the ashes. The figure for raw producer gas is close to 75 per cent and that of raw coal slightly above 80 per cent.

Some of the advantages to be gained from the use of one measure of heat value are indicated below. Ac-

counting is simplified since all distributions are made in terms of that unit. The relative importance of each heating operation becomes readily apparent. If a group of plants all follow the same system of measurement, their performances may readily be compared. For instance, our own corporation has three steel producing plants, each of which uses a considerable amount of natural gas which varies both in heat value and analysis in each plant. Comparisons made on the basis of cubic feet consumed would not be equitable, while the net MM Btu. basis takes into account both variables.

CONTROL OF FUEL SUPPLIES

It is highly important that sufficient control mechanism be set up to insure that both the quantity and quality of fuel supplies are maintained. This feature of fuel work should be tempered with common sense, however, as it is possible to build it up to a point where considerable money is spent for which there is little or no return. Plant conditions, source of fuels, basis of measurement, all conspire to dictate how far control should be carried. Our own experience over a number of years has led to a set-up which covers the needs of the situation adequately and still costs very little to operate.

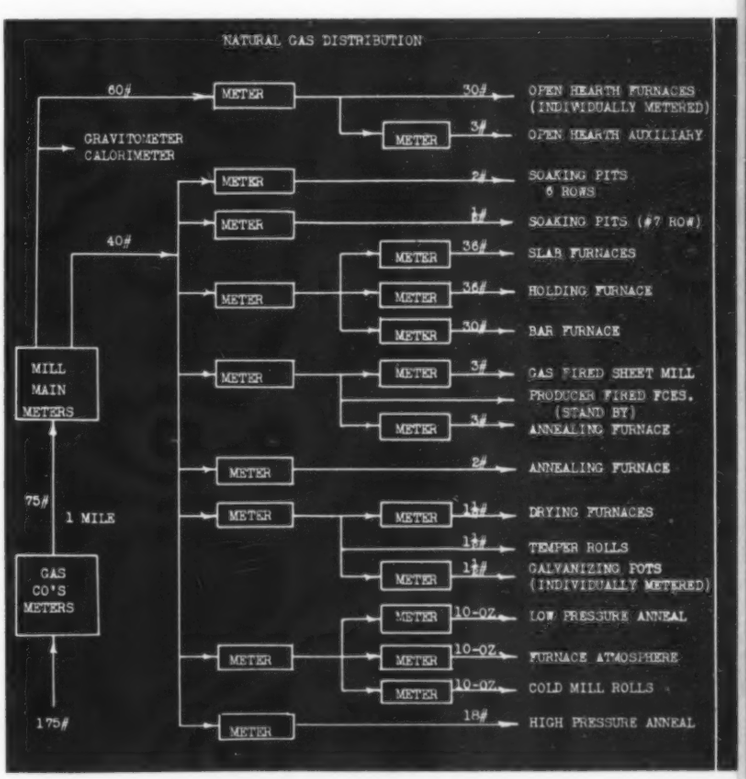
(a) Natural gas is supplied us on the basis of volume at stated conditions of temperature, pressure, and gravity. We measure our supply through rotary displacement meters which are equipped with temperature and pressure recorders and, in addition, an index which automatically corrects for both temperature and pressure fluctuations. A recording gravitometer furnishes a record of gravity. Heating value is checked by daily Sargent calorimeter runs on a sample accumulated over the entire 24 hours. The calorimeter installation deserves mention. The sampling gasometer, calorimeter, and water supply tank are all housed in a small, tight, brick shed. After a determination has been finished, the water supply tank is filled and the sample for the next day is started. Thus, it is possible to have gas temperature, water temperature, and flue gas temperature all at room temperature so that no corrections are necessary except those for thermometer stems. A complete check run can be made and computations completed within a half-hour's time.

(b) Fuel oil supplies are unloaded in a track pit and pumped into central storage tanks from which oil is distributed about the plant. Due to peculiar distribution conditions, the most important specification to us is that of viscosity. We have built a home-made viscosimeter to suit the oils we receive and have trained the unloaders to run viscosity tests on every car unloaded. They also report the dome measurements and the oil temperature for each car which serves as a check on quantity.

(c) Coal receipts are checked by running a daily composite sample collected in tightly covered cans, for moisture and ash. A cumulative sample kept from daily samples is run through the calorimeter weekly for heating value. With the data accumulated, it would be a simple matter to construct a composite chart against moisture and ash from which heating value could be read daily to a sufficient degree of accuracy for all practical purposes. The heating value of the coal as used for distribution and accounting is averaged from the weekly calorimeter determinations.

A careful record is kept of coal receipts and disbursements starting with shipment notices from the mine which are sent us daily. A report is given us each day by our local transportation department showing the number of cars received together with railroad weights which are accepted by us as the measure of coal received. Daily receipts are checked back against shipments, which furnishes us with a running check of the amount of coal in transit. Each coal-using department makes a daily report of cars unloaded from which cars are checked off the on-hand report and are at the same time posted together with their weight on a daily consumption form sheet made out for each department. Balances are struck weekly of consumption against receipts. After the weekly balance is struck, a requisition is placed on the mine for the shipments to be made in the following week based on the past week's consumption and a

Diagrammatic chart of natural gas distribution in the plant, showing metering set-up through which a constant distribution is maintained.



forecast of plant operations in the ensuing week. Stock pile inventories are maintained sufficient for a month of full operation and stocks are turned over once every two years. Stock pile withdrawals and additions are easily handled in the above routine. Under the system of weekly balances, errors are completely eliminated and distributions are accurate. In ten years, under this system, it has never been necessary to make an arbitrary adjustment in stock pile inventories for cause of shortage, and complaints from operating departments claiming overcharge are unheard of. Furthermore, the balance between shipments and consumption is balanced so closely that in spite of a four-day haul from mine to plant, demurrage charges for car service are never incurred. In fact, credits are built up from prompt unloading of coal cars which are depended upon to supply car service for other plant operations.

METERING SET-UP

The amount of money tied up in an adequate fuel metering system in a steel plant amounts in the aggregate to a very considerable sum but in the matter of metering, there can be no compromise. Every fuel consuming operation should have a fuel meter included in the installation just as surely as it must have a shut-off valve. Most of our operating and engineering departments accept this policy, but one of the fuel engineer's functions is to see that the meter is not forgotten when the bill of material is made up for a new installation. If the best use is to be expected from meters, some thought must be given to providing the proper type of meter for a given application.

Gas Meters—Each one of our trunk supply lines is equipped with recording and integrating orifice meters together with pressure and temperature recorders. The sum of the registrations of these trunk line meters properly corrected to base conditions of temperature and pressure balance daily with the total amount passed through the rotary displacement meters mentioned above. We have seven of these departmental trunk lines, no two of which are carried at the same pressure, the pressures varying from 16 oz. to 40 lb. Metering on the departmental lines runs through the whole range of displacement meter sizes up to three inches. This type of meter is used generally on small flows, say up to 3000 cu. ft. per hour, where the load conditions are periodic or where the fuel input is under full automatic control. For larger flows and especially where the load is more or less steady, orifice meters are used. Where the control is manual or semi-manual, indicators are provided as well as recorders and integrators. Registrations on departmental meters, properly corrected to base conditions, are made to balance the total trunk

DAILY OPEN HEARTH FUEL

Combustion Department

Heat No.	Tons	Lime	Pig	Start	Tap	Tap to Tap	Gal. Oil	Tap to Tap Btu.			Tons per Hour	Btu. per Ton	Delays		
								Act.	Std.	Eff.			H	M	Reason
81288	131	B	H	4:30P	4:10A	14:20	4140	579	543	94		4.42	2	10	Patch Roof
81289	141	R	....	4:50A	5:25P	13:15	4310	603	592	98		4.28			
82154	133	B	....	9:25P	8:50A	11:55	3900	546	586	107		4.11			
82155	141	.....	.....	9:20A	10:10P	13:20	4260	596	578	97		4.23			
83175	135	R	....	3:40P	1:50A	10:40	3380	473	567	120		3.50			
83176	130	B	....	2:20A	1:00P	11:20	3680	515	533	104		3.96			
85020	155	R	....	2:40P	1:35A	11:25	3460	484	636	131		3.14			
85021	151	.....	.....	2:05A	12:00N	10:25	3410	477	620	130		3.16			
85022	157	.....	.....	12:30P	10:45P	10:45	3260	456	636	140		2.90			
88048	167	.....	.....	5:20P	5:35A	12:45	4040	565	685	121		3.38			
88049	164	B	....	6:10A	7:00P	13:25	4180	585	705	121		3.57			
	1605					133.58		5879	6681	113.6	12.02	3.66	2	10	
17 Days	23948					2161.81		95829	100605	105.0	11.08	4.00	84	05	

line meter registration each day. Thus, a full balanced distribution is made each day. The registrations are posted on log sheets and at the end of an operating period, complete distribution is made by merely adding up the daily figures. Distributions are issued on the first day of the month complete to 8 a.m. of that same day. Variances between billing and distribution average 0.5 per cent and are taken up in cost.

Fuel Oil Metering—Total daily fuel oil consumption is arrived at by tank measurements taken at 8 a.m. each morning, taking into account car unloadings. Each consuming furnace is equipped with a displacement meter, the registration of which is used to establish distribution. No effort is made to correct for temperature, viscosity, or gravity since these conditions are so nearly alike on all our furnaces that a correction back to actual checked receipts is equitable enough for all practical purposes.

Coal—For applications using raw coal, equitable distribution can usually be established by keeping careful count of the number of lorry car or bucket dumps to each unit and prorating actual receipts by this count. Average weight per car or bucket can easily be established provided that personnel is trained to fill full at all times. If coal handling is organized to have all bins full at the same time each day and the count for the day is closed at that time, the distribution is kept independent of bin inventories.

If coal is used as producer gas, distribution is much more difficult especially if a number of furnaces with varying fuel demands are served from the same producer plant. It is possible to set-up distributions for producer gas that are to all intent equitable by striking average hourly fuel rates for each furnace and charging each furnace that rate for the hours worked. Periodically, usually at the end of the month, such distribution may be prorated to balance with the amount of coal used, this latter figure usually being dependable. In the course of time, by correcting average fuel rates on the basis of data secured when certain furnaces are idle or when various combinations are in operation, it is possible to make distributions which are accurate within 5 per cent. While the fuel practice on the whole shop may be kept fairly well in hand, it is nevertheless true that with the use of this fuel there is always a feeling of uncertainty—a fear that certain units may not be making the economies that they should because of the lack of accurate consumption data.

REPORTS

In connection with our fuel accounting, we issue reports as follows:

Daily Reports.

(a) The manager's office is given a report of fuels used the previous day and in the month to date, together with the fuel inventories on hand.

(b) Cost control clerk is given daily fuel consumptions which he incorporates in a daily plant cost report.

(c) A daily report of open hearth standard allowances and actual fuel consumption is made to the manager, general superintendent, chief engineer, and the open hearth superintendent.

(d) Actual fuel consumptions are reported to all superintendents whose departments use sizable amounts of fuel.

Weekly Reports.

(a) Weekly summary of fuel consumption, receipts, and inventories is made to the manager's office.

(b) Weekly balance of coal receipts, consumptions, and inventories, together with a requisition for the following week's supplies is made to the manager, purchasing agent, and mine superintendent.

(c) A running record of plant fuel performance against standards in chart form is shown in the weekly superintendent's meeting.

MONTHLY REPORTS

(a) Distribution reports for gas, oil, coal, oxygen, and acetylene are issued to accounting department.

(b) A fuel audit report for the entire plant showing production, standard fuel allowances, and actual consumptions are issued to operating superintendents, manager, general superintendent, and to the management of associated plants. This report serves as the measuring stick of fuel performance and has been in use in its present form in all three of our steel plant divisions since 1932, with very good success.

At the beginning of each year, a summary is made of the year's performance and stock is taken of either improvement gained or the ground lost during the year.

STANDARDS

Together with the advent of the present fuel audit in 1932, a system of fuel standards was set up for all major fuel users. The first attempt at this was a rather crude affair since there were no criterions of performance available and since plant conditions at that time were in the state of transition from the old-time style of sheet mill working from sheet bar to the hot strip mill with all its attendant ramifications. For some operations, the only basis available for setting standards was that of a theoretical heat balance. For others, sufficient actual fuel consumption data was available to form a practical basis. In still others, we found it advisable to use a heat balance as a check on actual performance, or vice versa. The first set-up covered the open hearth, soaking pits, and finishing mill only, but as time went on, other operations were added until at the present time, the entire plant is covered.

The first standards which were set up allowed simply a lump amount of fuel per unit of production. As time went on and we had opportunity to see how the applications worked out, we found wide discrepancies occurring for which it was difficult to account. Analysis soon

made clear the fact that plant operating conditions sometimes introduced factors which had a considerable effect on fuel performance. For instance, an open hearth furnace might be taken out of production for

COMPARISONS—ACTUAL TO STANDARD

DEPARTMENTS	Avg. 1937		July 1938				August 1938			
	Prod.	Act.	Prod.	Std.	Act.	Eff.	Prod.	Std.	Act.	Eff.
OPEN HEARTH*										
No. 1 Furnace	5203	4.253	5789	4.247	4.088	103	7439	4.229	3.857	110
No. 2 Furnace	5530	4.021	6264	4.148	4.036	103	8015	4.235	3.985	106
No. 3 Furnace	5961	4.253	3757	4.253	3.889	109	8556	4.262	3.891	110
No. 4 Furnace	5993	3.917	5961	4.153	4.394	94	7388	4.207	3.393	124
No. 8 Furnace	6527	4.267	2849	4.049	3.684	110	9020	4.140	3.734	111
Average Melting	49716	4.065	24620	4.209	4.072	103	42944	4.209	3.816	110
Auxiliaries	49716	.180	24620	.159	.154	101	42944	.190	.156	122
Shut-Downs	49716	.087	24620	.324	.320	103	42944	.....	.....	...
TOTAL—OPEN HEARTH	49716	4.332	24620	4.692	4.546	103	42944	4.399	3.972	111
BLOOMING AND BAR MILL										
Soaking Pit—Operate	47407	.886	28445	1.081	1.408	77	32885	.932	1.192	78
Soaking Pit—Warm Up	47407	.086	28445	.447	.581	77	32885	.315	.404	78
Slab Furnace—Operate	45676	.717	27975	.967	1.089	89	32132	.977	1.114	88
Slab Furnace—Warm Up	45676	.166	27975	.372	.392	95	32132	.330	.317	104
Holding Furnace—Operate	45676	.133	27975	.145	.156	93	32132	.146	.136	107
Holding Furnace—Warm Up	45676	.026	27975	.042	.043	99	32132	.044	.036	122
FINISHING MILL										
Finishing Mill—Operate	26460	2.024	15139	2.044	2.201	93	18437	2.039	2.156	95
Finishing Mill—Warm Up	26460	.136	15139	.300	.256	127	18437	.275	.275	100
H. G. Anneal—Operate	6940	1.757	4065	1.658	1.776	93	4346	1.696	1.892	90
H. G. Anneal—Warm Up	6940	.065	4065	.123	.148	83	4346	.184	.171	108
PROCESSING										
Normalizer—Operate	4475	3.053	4035	2.900	3.162	92	4669	3.065	2.816	109
Normalizer—Warm Up	4475	.029	4035	.048	.051	95	4669	.056	.043	131
New Anneal	10107	1.211	6011	1.587	1.377	115	5423	1.635	1.527	107
Individual Anneal	9980	2.183	2667	2.404	2.696	89	3721	2.314	1.978	117
Continuous Anneal	5898	1.475	7826	1.157	1.077	107	6499	1.170	1.176	99
Bright Anneal	11835	.110	8323	.215	.300	71	7368	.215	.261	83
GALVANIZING										
Spelter—Operate	8083	.697	6982	.700	.774	90	7977	.700	.743	94
Spelter—Warm Up	8083	.053	6982	.066	.066	100	7977	.048	.048	100
Alloy—Operate	3371	.851	1563	.850	.716	119	2131	.850	.738	115
Alloy—Warm Up	3371	.032	1563	.120	.120	100	2131	.046	.046	100
BOILERS										
East Works	196264	1.294	120604	1.375	1.495	92	134744	1.342	1.471	91
Central Works	12028	1.316	5160	.....	1.345	...	4563	.....	1.494	...

a week but still be kept hot enough to protect roof and banks. The amount of fuel so used would be sufficient to turn what really should have been a very good fuel figure into a poor performance. Soaking pits and slab furnaces may have had a short operating week which meant a long shut-down and made necessary a longer heating-up period with increased amount of warm-up fuel. In turn, this increased warm-up fuel had to be charged against the smaller production tonnage resulting from the short operating week. In the finishing mill, good size and weight orders would result in excellent fuel performance but might be followed by difficult orders which would show poor fuel practice.

In the course of time, allowances have been set-up for all such conditions which might have sufficient influence on fuel performance to merit consideration. In a good many cases, this was found difficult since fuel consumption records were not kept in sufficient detail to establish the values involved but the very fact that the heat allowances were made led to more detailed fuel accounting, which soon brought out any shortcomings. Thus, in time, values were worked out which were entirely equitable.

A summary of standard fuel allowances is shown below:

Open Hearth—Melting standards are set for seven grade classifications, two furnace sizes, and for either hot or cold metal practice, or a total of twenty-six items. Additional allowances are made for pit fuel or that used in ladles, runners, and stopper rod oven, for hours that an idle furnace is held warm, for a warm-up after a hot repair, and for warm-up of a cold furnace.

Soaking Pits—Operating standards are allowed for three grade classifications and for either hot or cold ingots. Allowance is made for fuel used to hold ingots in condition to roll after satisfactory heating has been reached, in case of unforeseen mill delays. Weekly warm-up allowances are set up for five different lengths of shut-down.

Slab Heating and Holding Furnaces—The fuel rate per hour on this furnace is much more nearly constant than is the mill production, so operating fuel standard allowances are set on the basis of fuel per operating hour rather than on fuel per ton. Allowances are made also for holding furnaces warm during a mill shut-down, and for hot or cold warm-ups.

Finishing Mills—Standards are set on the basis of fuel per net ton of finished sheets and vary according to the size and type of mill. Allowance for hot or cold warm-up is made for each furnace. Thirty items.

Annealing—The basis is fuel per net ton sheets. For one group of furnaces, seven allowances are made according to cycle. In another group, sixteen allowances are used, depending on the size of furnace and the width of charge. Allowances are also made for various warm-up conditions.

Galvanizing—Standard operating allowance is on the basis of fuel per net ton galvanized. Allowances are also made for holding warm over shut-down, for bailing over, and for warming up a cold furnace and bath.

It will be clearly evident from this short summary that the application of a comprehensive set of standards involves considerable detail both in set-up and use, but once established, the work becomes routine and the cost is negligible in light of the benefits gained. Once established, fuel standards should be kept alive by reviewing them periodically, at least once each year and making revisions as indicated in the light of changes in plant or practice, or improvements attained in performance. They should be kept tight enough that 100 per cent performance cannot be easily attained but still fair enough that they can be approached by good practice. Very little attention will be given by operating men to a standard which is impossible of attainment, hence, such a standard will have little value. When used fairly and intelligently, standard allowances are a very useful tool for the fuel engineer. Should the plant management consider it expedient to give special consideration for good fuel performance, a set-up of standards provides a very good measuring stick.

For several years, the three main plants in our corporation have been comparing fuel performance each month. Rivalry has been keen and each plant has made sustained efforts to equal or excell the records made in other divisions. Direct comparisons were possible since the same sets of values were in use in all three plants, tempered only by the differences in heating value peculiar to the fuels in local use. Since the cost of fuels varies so greatly in different locations which would make direct cost comparison impracticable, all comparisons have been made on the basis of fuel consumption alone. Hence, direct comparisons could be made readily so that spots of weakness existing in any plant soon became apparent and special attention could be given to them. Under this set-up, some striking improvements have been accomplished.

It is entirely within the realms of possibility that a similar plan could be extended to include even a larger number of plants engaged in the manufacture of similar products, which would inevitably benefit all participants. All data would be expressed in terms which would have comparable values and would be readily understood. Comparisons made of performances in different plants would show a true picture of what was being accomplished. Poor performance in any particular plant would quickly be made apparent so that concentration of attention could be focused on that point. Plants in which good fuel practice had been developed would soon realize that their attention must be sustained if their standing is to be maintained. The relative merits of various types of furnaces or combustion systems or control set-ups could be established. Better contacts and understandings between various plants would be promoted which would have value in light of the growing feeling in the steel industry that salvation lies in a unified group effort towards making better products at lower cost.

The first step in such a program would be the delegation to an interested agency, or committee, of the responsibility of setting up a comprehensive plan or basis for fuel performance reporting and gaining the cooperation of enough plant managements to insure success. Each plant would report performances periodically to this agency which would tabulate the data and make up a report with plant identities concealed, which would be sent back to all participants.

DISCUSSION

PRESENTED BY

F. E. LEAHY, Fuel Engineer, Youngstown Sheet and Tube Company, Youngstown, Ohio.
HARRY DOBRIN, Pennsylvania Industrial Engineers, Pittsburgh, Pennsylvania.
A. J. FISHER, Fuel Engineer, Bethlehem Steel Company, Sparrows Point, Maryland.
G. M. COUGHLIN, Combustion Engineer, American Rolling Mill Company, Ashland, Kentucky.
M. J. CONWAY, Fuel Engineer, Lukens Steel Company, Coatesville, Pennsylvania.
E. T. W. BAILEY, Combustion Engineer, Steel Company of Canada, Ltd., Hamilton, Ontario, Canada.
H. V. FLAGG, Combustion Engineer, American Rolling Mill Company, Middletown, Ohio.

F. E. LEAHY: The paper on "Steel Plant Fuel Accounting" by Mr. Flagg is a very excellent contribution on this very important subject. Mr. Flagg has carried this work to greater details than any others that I have known personally.

We have established standards for various departments and in doing this have discovered that daily information for purposes of control have been very valuable in securing uniformity of results. It is quite noticeable that the departments using the daily figures have been able to very substantially improve their practice.

In order to carry out the plan as outlined by Mr. Flagg, it is necessary to establish and maintain a very excellent system of metering. By careful planning, such a system can be established at a surprisingly low cost for maintenance and service.

Mr. Flagg's description of their method of checking and distributing coal to their various departments is very interesting and shows how such a difficult problem can be successfully handled.

Those who have attempted to make comparisons with the practice in other plants have frequently had difficulty due to local variations in distribution practice and basic figures used. If such a plan as outlined here could be set up to satisfactorily compare the plants within this corporation on quite an exact basis, it proves that it could be carried further into plants outside this organization, if the same basic methods were adopted.

I think this subject is worthy of very serious consideration and would suggest that additional studies on this subject be made with this purpose in view. I believe a committee on standards and distribution should be established by the Association to recommend methods and practice for establishing interplant comparisons. This would supply a long-felt want to those whose duties are to supervise and maintain good fuel and furnace practice.

In conclusion, I again wish to compliment Mr. Flagg on this paper which I believe should be the beginning of a plan for securing a better understanding between plants of their comparative practices.

HARRY DOBRIN: We had, at one time, heard down in Birmingham that a certain furnace in the Pittsburgh district was using only 900,000 Btu. for heating a ton of cold billets for rolling, and I immediately came to Pittsburgh to see this wonder furnace. When I got to the plant and I asked, "Where is this billet heating furnace?" I was brought to the location of the furnace and the first thing I wanted to see was the meter and when I asked, "Where is the meter to this furnace?" the reply was, "We haven't had a meter on this furnace for the last two or three years." This about sums up the manner in which fuel figures and fuel practice used to be reported at one time when no attempt had been made for any such difficult proposition as standardization.

There was one question asked of Mr. Flagg as to the incentive furnished the various operators in order to save fuel. I happen to be familiar with the method and also with this particular problem. The plan calls for putting all standardization in terms of Btu. per unit of production, for each furnace unit as well as each department, and allowing for differences of many factors in each different plant, various standards are set up for performance of a particular furnace unit. This is called an "ideal standard".

The ideal standard has no relation whatever to theoretical efficiency. The ideal standard represents a performance which is attainable, so that if a furnace should do a certain job for 2,000,000 Btu. per ton, even though the theoretical efficiency may be only 500,000 Btu., nevertheless the 2,000,000 attainment would be considered an ideal standard. In this way an ideal standard attained to 100 per cent is a figure that could be eventually achieved and the men are very proud of the fact when they do so.

Periodically, the standards are revised, so that when a certain performance continues to meet and exceed the ideal standard, such standard is advanced. In the same way, if a certain standard has been unduly high and if operation continues to fall very far short of its attainment, the standard is lowered.

In setting these standards, allowance is made for the condition of the funace, for the type of fuel that it uses, to the end that if one furnace unit in one plant uses a highly concentrated fuel like natural gas or coke oven gas and a similar operation is being performed in another plant by means of producer gas, the theory is that each one should be able to attain the ideal standard even though entirely different figures and expectations are determined.

At the end of each month, the superintendent of each department is given a slip showing him the results of his own department as well as the results on each particular individual furnace unit which is within his jurisdiction. It is a fact that these men will carry these slips around with them and are proud of any

good showings that they make. Under such conditions, the men become extremely fuel-conscious and if there is a way for them to save any fuel, you can depend on it that they will do so because there is a very healthy rivalry in the organization. Under such conditions, the operating heads of the organization are aware daily and hourly as to the heat units that they use per unit of production.

A. J. FISHER: We have found two items of importance in fuel accounting. The first one is to meter all the consumers and to charge each department the exact amount of fuel consumed, regardless of whether the practice for that particular month is good or bad. Due to the large number of fuel users in a steel plant, it is entirely possible by means of the diversification of load, to average out conditions in order to save the explanation of poor practice to the management for the particular month in question. It is far better, in the light of future economy to have a complete discussion at the time, than to cover up and keep things quiet. The second item is to post the daily fuel rates, in the case of heating furnaces and the fuel per heat in the case of melting furnaces, at the furnace so that the heaters will see what they are doing and consequently arrive at conditions where the least amount of fuel to do the job is used.

G. M. COUGHLIN: I am sure that many who have just heard this paper will wait anxiously for its publication, so they can analyze more thoroughly the ideas presented and adapt many of them to their own system, and thus receive those benefits which accrue from such practice.

The plan used by Mr. Flagg is a far cry from the old method of paying the monthly fuel bill and then roughly and most arbitrarily distributing the charge piecemeal among the various fuel using departments. The old method has little to recommend it. No incentive is offered to an economically minded superintendent, foreman or heater, to take steps toward a more careful use of fuel. In fact, with such a distribution plan in use there is no way for a superintendent to determine the effect on fuel costs of any change he might make in operations. The effect on the fuel bill easily could be lost due to variations in other departments. Such a plan certainly discourages economy. How different is the position of the superintendent who knows, at the end of each 24 hours, not only the fuel consumption in the department, but the Btu. used per ton produced and the actual fuel cost for each ton of product handled by his department that day and then compares the actual cost to his standard cost for that product.

One plant goes so far as to report the Btu. per ton for each furnace to the department at the end of each turn or after each open hearth heat, and within an hour of the end of the turn. The figures then are posted by the foreman on the furnace bulletin board to keep the heaters informed.

With such information available the furnace tender, the superintendent, and the combustion engineer are able to analyze the results of each change made on the furnace and are always in a position to take full advantage of all opportunities to reduce the fuel costs. To plan properly for and to install such a system is a big and sometimes an expensive job; but it can be done a little at a time if necessary.

To maintain the system, to keep the meters in calibration, to see that the accounts are reported accurately and kept properly is vital to the success of the undertaking. But vigilance in this case gains the reward—lower and lower fuel costs and the friendly and grateful support of the management.

Mr. Flagg has spoken of the friendly rivalry among the different plants, which is of benefit to the company in lower fuel costs in all divisions. This has led to his suggestion that the Association might foster such a rivalry among its members in many of the plants in this country. Such a plan, if carried to its conclusion could have far-reaching benefits to many companies. If the plan can be worked out successfully, management will be given a new standard with which to measure their fuel costs.

M. J. CONWAY: Referring to Mr. Flagg's suggestion that comparisons be made on the net heating value of the fuel expressed in MM Btu., I believe that the therm or 100,000 Btu. would be the better denominator. The use of the therm in expressing numbers of Btu. is becoming increasingly used by government statistical departments and utilities, and is also recognized by several state Public Service Commissions as an equitable measure by which gas can be sold to the consuming public.

I was particularly interested in Mr. Flagg's reference to fuel oil metering noting that no attempt was made to correct for temperature on the individual furnace but applying a common correction factor to check back to actual storage "plus innage less outage".

If temperature was the only condition to allow for, then the fuel oil accounting would be comparatively easy, as all that would be necessary would be the use of a recording thermometer to set up the factor, but we have a much greater difficulty to solve, that of meter inaccuracy, either due to change of rate of flows, maintenance neglect or other causes.

Until recently, oil was the chief fuel used at our plant and the metering of this fuel has given us plenty of headaches, in addition to our troubles in the metering of oxygen. Where coke oven gas or natural gas is used, these metering inaccuracies are not as great and equitable daily distribution for accounting purposes is possible.

Mr. Flagg's suggestion that a committee could be formed to set up values for inter-company fuel comparisons is well taken, and I know of no better agency than the Association of Iron and Steel Engineers to undertake this work.

E. T. W. BAILEY: The plan of daily posting and balancing is followed by us insofar as gas and fuel oil are concerned. Practically all our coal goes direct to the coke ovens.

As Mr. Flagg has pointed out, any attempt to set up a basis whereby different fuels may be compared is well-nigh hopeless. In the third edition of Industrial Gas Series "Combustion", published by the American Gas Association, the following paragraph appears:

> "In American gas practice, data on efficiency of operation are based on the gross heating value of the fuel, on the theory that efficiency really is

defined as output divided by input, even though it may be physically impractical to condense the water vapour in actual appliances. Moreover this method is quite justified, because no practical appliances operate under 150 degrees F. It would therefore be just as logical to define heating values on the basis of the heat recovered to this practical minimum flue temperature, disregarding the sensible heat in the flue gases from 150 degrees F. down to the starting temperature, as well as the latent heat of condensation. Since this practice could not be countenanced, it is considered that no single item must be disregarded, and the gross heating value is employed."

This point among others would have to be settled by a standards committee if an exchange of values between plants is to come into effect.

Standards for allowances of fuel for various heating demands other than actual operating loads would take a long time to establish in each plant. In many cases they would have to be established for different fuels applied to the same furnace. One can think of a number of furnaces, where mill delays on small orders, frequent changing of fuel and stock, furnace being brought to temperature before and after charge is in place, all sorts of hours of operation that would make the problem of obtaining standard allowances hopeless. Even if figures were finally obtained the furnace operator would have to be depended upon to furnish the data required to post results, the furnace operators, as a rule, do not make good bookkeepers.

A means of exchanging fuel performance data among steel plants as suggested by Mr. Flagg would be of great value and it is to be hoped that some effort will be made to bring this into being.

H. V. FLAGG: It occurs to me that one point arises from the discussion of this subject that may well be restated and given additional emphasis. A good fuel accounting system, like any other development of merit, is usually built up over a considerable period of time, and results from the cooperative effort of several different agencies. The various departmental operating staffs, the works accounting department, the production standards division, as well as the combustion engineer, all must contribute their share. It follows that no one individual or agency can build up such a system nor claim the credit for it when finally worked out. Nevertheless, it is necessary that there be some central agency to direct and correlate the efforts of all the agencies involved.

Mr. Leahy's emphasis on the need for standardization of fuel accounting in order that comparisons between various plants might truly reflect the relative performances is timely.

Mr. Dobrin's comment concerning the use that can be made of fuel standards to keep operating men informed of their fuel use and performance was all quite true and amplified a point merely mentioned in the paper.

The necessity for accurate accounting was emphasized by Mr. Fisher. Manipulation of fuel charges either to cover up poor performance or to tone down exceptionally good performance, destroys measurement balances and gives an untrue picture of performance which usually at some later date backfires with embarrassing results.

Since Mr. Coughlin's work and my own are both organized under the same system, it is to be expected that we should agree in principle. Certainly the establishment of standards and uniform accounting for a large number of plants would be a difficult task, but it is probable that the recognized difficulty involved is evidence of the need for it and the benefits to be gained from it.

Mr. Conway's suggestion that the therm be adopted as the unit of heat consumption is worth consideration since this unit is already in wide use and merely involves one point change in decimal place.

Mr. Bailey's contention that consumers should be charged with the total potential heat in the fuel used has many backers and is quite satisfactory so long as but one fuel is involved. However, when comparisons are to be made involving the use of different fuels on the same class of work, inequalities develop which reflect unfavorably on performance of the unit. The use of net heating value does eliminate the one variable of water loss in flue gases which is inherent in the type of fuel used. As Mr. Bailey suggests, standardization of fuel heating values would be the first task of the agency set up to work out uniform fuel accounting and might very well be the first point of attack in such a project.

NEBLETT DISCUSSION

(Continued from page 20)

stalled. In our first installation we did have some perforations in the bottom electrodes to allow the sludge to go to the bottom. We found this a detriment because the sludge would go down through the electrode and settle at the bottom. It is hard to remove, is heavy and sluggish and you can't get it out. We changed this and put in a solid bottom electrode flush with the bottom of the tank which enables the sludge to be removed more readily.

I think Mr. Hooker, in his discussion, has described for us a process that deserves full consideration in future installations.

Mr. Brown mentioned the problem of lead sulphate accumulating on sheets. This can be a problem. If you let the sludge build up in the tank to a point where it will come in contact with the strip, you will get a deposit of lead sulphate on the sheet which is detrimental. The sheet is carried on supports which do not allow it to touch the bottom and this will not occur unless there has been negligence in removing the sludge from the tanks. I mentioned our experimentation with graphite electrodes which will naturally eliminate the lead sulphate and we hope have many other advantages.

Mr. Ranney brought out the question of the speed value in comparison with more recent design. More recent installations do have a higher speed than we have. We have increased the speed of this unit and could further increase it by means of scale breaking equipment. We have installed some scale breaking equipment on this line as an experiment and it did increase the speed. Due to some mechanical defects with the particular kind of scale breaking equipment which we installed, it is being dispensed with for the present, but we expect, in the near future, to install scale breaking equipment that will further expedite and speed up the pickling action.

EFFICIENCY *of the* BLAST FURNACE PROCESS

By J. B. AUSTIN

Research Laboratory

United States Steel Corp. of Delaware

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▲ IN considering so complex a process as the smelting of iron in the blast furnace, there is obviously no single method of calculating efficiency that gives a complete appraisal of the performance of the furnace in all its several functions; such a comprehensive view as is required to evaluate producing ability and manufacturing costs for a given furnace is obtained only by considering a group of efficiencies, each of which measures the performance of the furnace from a specific point of view. For instance, there is a rate of consumption of coke per ton of iron produced, which is probably the most frequently considered, and is certainly one of the most important of the group; there is the efficiency of recovery of iron charged; and there is the efficiency of utilization of energy, both chemical and thermal, in some respects related to the former two yet in other ways independent of either. In each of these cases, the calculation can be made on the basis of the actual input of material or energy, or it may be based upon a comparison with the minimum amount of material or energy that would be required by a "perfect" furnace; that is, an imaginary ideal furnace analogous to the perfect steam engine used in thermodynamic calculations, when this furnace is operating under optimum conditions. Moreover, the furnace itself can be considered either as an apparatus for smelting iron or, taking a somewhat less common point of view, as a gas producer yielding iron and slag as by-products. Some of these efficiencies are more useful than others, yet all are instructive; for a knowledge of them not only leads to good engineering practice from the standpoint of control but also discloses limits to possible improvement in performance and indicates the lines along which improvement is most likely to be profitable. Estimates of some of these efficiencies have appeared from time to time in the literature, but many of them are open to objection because they are based on data of uncertain accuracy or because they have been calculated without due regard to the thermo-dynamic principles involved. Moreover, so far as the author is aware, no general survey of the blast furnace comparing its performance in all the aspects mentioned has been made.

It is the purpose of this paper to consider and to compare these several efficiencies as calculated from the most reliable data now available. Clearly, a complete and detailed study of such a broad subject can scarcely be contained in anything smaller than a book, so that no attempt is made to supply detailed calculations in every instance; the aim is rather to present a point of view, chiefly as regards the performance of a perfect furnace, with only occasional resort to numerical values, leaving detailed calculations to be carried out by the reader for the cases in which he may be interested. The discussion contains little that is new, most of it having been given before by others, though usually in somewhat different form, but repetition is justified by the fact that misunderstanding of the fundamental role played by chemical and thermal equilibria in the smelting process continues to exist. The author, realizing that many limitations of practical operation have been neglected, wishes to emphasize that this discussion is not intended to be a manual for operating a furnace, but seeks to derive from established chemical and physical principles some idea of the performance achieved by a perfect furnace; in other words, an attempt is made to set up a par value or bogy with reference to which the performance of a real furnace can be compared.

But before evaluating the blast furnace in terms of perfect performance, it is interesting to see how the efficiency of this furnace, which uses coke both as a fuel and as source of reducing agent, compares with that of other possible processes in which a different method of heating or a different reducing agent is used. This can be done conveniently by considering the principal functions of an iron smelter, which are: (1) drying and preheating the charge; (2) calcination of carbonates and fluxing of gangue materials; (3) reduction of metallic

oxides in the ore; (4) melting and superheating the iron and slag produced.

Three of these items—namely, preheating, fluxing and melting—are essentially heating operations for which the heat requirement is essentially the same in all processes producing pig iron, since the heat that must be supplied is fixed by the nature of the charge and the grade of iron being produced, and is independent of the method of heating used. The same is true of the important factor of the temperature attained in the hearth, since this is also determined by the grade of iron produced and is independent of the method of supplying the heat. Consequently, as far as these operations go, all methods capable of supplying the necessary amount of heat and the required temperature are in principle equivalent. Any advantage of one over the other that appears in practice is due to an advantage gained in the design of equipment or to an economic factor such as a much lower cost of one form of heating in a given locality. Inasmuch as the blast furnace, using coke as fuel, produces both the amount of heat and the temperature required, and conserves each throughout the process with relatively small loss, it satisfies the requirement and is therefore in principle as efficient thermally as any other method. From an economic standpoint it is superior to other methods in locations where metallurgical coke is produced in sufficient quantity at a relatively low cost.

The situation is somewhat different with the fourth function, the chemical operation of reducing metallic oxides, because here the amount of heat required differs widely with different reducing agents. This is illustrated by the data in Table 1, which give for two temperatures the heat absorbed (positive) or evolved (negative) in the reduction of 1 lb. of iron from Fe_2O_3 by hydrogen, by carbon, and by carbon monoxide, the only reducing agents likely to be commercially feasible. With hydrogen there is a small absorption of heat, with carbon a large absorption, but with carbon monoxide the reaction is exothermic and there is a small evolution of heat. From a purely thermochemical standpoint, therefore, reduction by means of carbon monoxide, which results in a slight gain in heat, is better than reduction by either carbon or hydrogen, in which heat must be supplied to keep the reaction going. On this same basis, reduction with carbon monoxide itself is obviously better than with a mixture of carbon monoxide and hydrogen.

TABLE 1.—*Heat Absorbed (Positive) or Evolved (Negative) in Reducing One Pound of Iron from Fe_2O_3 by Means of Different Reducing Agents*

Reaction	Heat Effect, Btu. per Pound Fe	
	At 70° F.	At 1650°F.
$Fe_2O_3 + 3H_2 = 2Fe + 3H_2O$	502	134
$Fe_2O_3 + 3C = 2Fe + 3CO$	2,334	2,076
$Fe_2O_3 + 3CO = 2Fe + 3CO_2$	—92	—339

Summing up over all the operations carried out in smelting iron, it is clear that reduction with carbon monoxide as carried out in the blast furnace is in principle much the most efficient way of producing pig iron. This superiority becomes even more marked when one considers that in the blast furnace the coke produces heat and high temperature at the place where they are most valuable, that is, in the hearth, and at the same time supplies carbon monoxide, which is the most efficient reducing agent. The blast furnace, therefore, is much more efficient thermally than a process in which the reduction is carried out by carbon monoxide with some source of heat other than burning coke, and this in turn is better than a process using carbon or hydrogen as the reducing agent. Indeed, the high efficiency of the blast furnace compared to other iron-smelting processes that have been proposed from time to time is due to the very efficient way in which the carbon and carbon monoxide are used.

RECOVERY OF IRON

Considering the blast furnace as a smelter, the first efficiency to be considered is the recovery of the iron charged. In all modern furnaces more than 90 per cent of the iron in the charge is recovered directly as pig iron, a yield that is remarkably good for a single operation, there being relatively few chemical reactions carried out on a large scale that can approach it. In fact, it would often be considered a satisfactory recovery for a process that includes the working of waste materials. The only metal losses are in slag and in flue dust, and as the latter is usually returned to the furnace as dust or as sinter the net efficiency may, and often does, exceed 95 per cent.

CONSUMPTION OF CARBON

Turning to the question of coke consumptiom there is an immediate difficulty in selecting a proper basis on which to calculate the efficiency, because coke serves as both fuel and chemical reagent; that is, it not only supplies heat but is the reducing agent as well. As the demands of both these uses must be met, it is logical to select as a basis the one that requires more carbon, because this is the use that in actual operation fixes the amount of coke consumed. The problem becomes, then, one of determining, or at least approximating, the amount of carbon required as fuel on the one hand and as reagent on the other.

A calculation of the amount of coke required as fuel is not a simple matter; indeed, it is not even a definite problem because combustion of coke is not the only source of heat in the furnace. An appreciable fraction of the total heat is brought in by the hot blast, which incidentally, is one of the means commonly employed to regulate the heat supply. Nor is the total amount of heat required the only consideration. Other factors that must be taken into account are: (1) the place where the heat is supplied, since economical operation depends upon a proper balance between the heat generated in the hearth zone and that required in the hearth as well as in the reducing zone; and (2) the temperature at which the heat is delivered, because this heat, to be effective, must be furnished at,

or above, some minimum temperature, which is largely determined by the grade of iron being produced. It appears therefore somewhat simpler to calculate the minimum amount of coke required for reduction and then to see whether the heat generated by this coke in combustion, plus the heat that can be conveniently brought in by the hot blast, is sufficient to supply the requirements of the furnace.

CARBON AS A SOURCE OF REDUCING GAS

Considering carbon as a chemical reagent, it is possible to base an efficiency for the over-all reduction of iron from Fe_2O_3 on the stoichiometric relations expressed in the equations

$$Fe_2O_3 + 3C = 2Fe + 3CO \quad [1]$$

$$Fe_2O_3 + 3CO = 2Fe + 3CO_2 \quad [2]$$

which show that 720 lb. of carbon, either as coke or as carbon monoxide, react with 3210 lb. of Fe_2O_3 to give 2240 lb. of iron. Thus, the efficiency can be defined as the ratio of this amount of carbon to that required in an actual furnace. But such a procedure is misleading because it implies a possibility that a ton of iron can be obtained in practice with an expenditure of only 720 lb. of carbon, which is not true except under very special circumstances. It can be done if all the reduction is "direct"; that is, if it is carried out by direct reaction between carbon and the iron oxide, so that the carbon monoxide formed escapes—as, for instance by letting an oxide slag react with a bath of molten iron saturated with carbon.*

But it cannot be done in a blast furnace or any other apparatus in which all, or nearly all, of the reduction is carried out by means of carbon monoxide, because equilibrium conditions make it necessary to maintain a considerable excess of carbon monoxide in order to keep the reaction going in the desired direction and to prevent its reversal, which would mean reoxidation of iron by the carbon dioxide formed. Any conclusion drawn from the calculation of such an efficiency is therefore erroneous when applied to blast-furnace reactions, in precisely the same way that the efficiency of a steam engine would be wrongly stated if calculated without regard to the theoretical efficiency of the cycle on which the engine operates. A more accurate evaluation of performance, for the blast furnace as well as for the steam engine, is obtained by calculating a relative efficiency based on the performance of some furnace, or engine, which operates in such a way that it achieves the maximum utilization of energy, chemical or thermal, permitted by the second law of thermo-dynamics. For the steam engine, the Carnot cycle provides such a standard efficiency, but no corresponding measure has as yet been established for the blast furnace, although an approximate one—which is in essence identical with the Carnot cycle—can be set up, as is shown below.

The development of this standard is most easily understood by starting with a consideration of equilibrium in the reaction between ferrous oxide and carbon monoxide, which, in so far as coke consumption is concerned, appears to be the most important reaction occurring in the blast furnace, because of the large amount of carbon required to carry out this last step in the ore reduction. The so-called equation for this reaction, that is,

$$FeO + CO = CO_2 + Fe \quad [3]$$

is nothing more than a statement in chemical shorthand that whenever one formula weight of ferrous oxide is reduced one formula weight of carbon monoxide disappears and one formula weight of carbon dioxide and one of iron appear. Or it may with equal validity be applied to the oxidation of iron by carbon dioxide, for which it states that when one formula weight of carbon dioxide reacts with a formula weight of iron, one formula weight of carbon monoxide and one of ferrous oxide are formed. In other words, it is in effect a specialized statement of the law of conservation of matter, and is analogous to the law of conservation of energy.

The equation does not imply that all mixtures of carbon monoxide and carbon dioxide will reduce ferrous oxide, any more that it implies that all such mixtures will oxidize iron. In fact, it tells nothing whatever as to which mixtures are oxidizing or reducing in relation to either iron or ferrous oxide. Moreover, it makes no mention of temperature, yet there is a whole range of mixtures of carbon monoxide and carbon dioxide that will be reducing at one temperature and oxidizing at another. In order to predict the behavior of a given mixture, it is necessary to know the equilibrium mixture for the reaction at the temperature in question, and this can only be determined by direct experiment or by thermo-dynamic calculation if the necessary thermal data for the several substances involved in the reaction were available. If at a particular temperature a given mixture contains a higher concentration of carbon monoxide than the equilibrium mixture at that temperature, the mixture will tend to reduce ferrous oxide and not to oxidize iron; conversely, if it contains more carbon dioxide than the equilibrium mixture, it will tend to oxidize iron but will not reduce ferrous oxide.

Direct measurements of the equilibrium in this reaction show that at the temperatures prevailing in the lower part of the blast-furnace stock column only about one-third of the total carbon monoxide is available for reduction. To take a specific example, if a limited volume of pure carbon monoxide is brought into contact with a mixture of ferrous oxide and iron at 1650 degrees F. (900 degrees C.) reduction of ferrous oxide proceeds, rapidly at first but at a decreasing rate as carbon dioxide accumulates in the gas, until the gas has attained a composition of 68 per cent carbon monoxide and 32 per cent carbon dioxide, when reaction ceases. If we start with a limited volume of pure carbon dioxide there is oxidation of iron, again at a decreasing rate, with cessation of reaction when 68 per cent of the carbon dioxide has been converted to carbon monoxide. This mixture of 68 per cent carbon monoxide and 32 per cent carbon dioxide is therefore in equilibrium with ferrous oxide and iron at 1650 degrees F. (900 degrees C.) and represents the maximum possible utilization of carbon monoxide in the reduction of ferrous oxide at that temperature. The residual carbon monoxide is unavailable in this reaction in precisely the same way as the units of sensible heat in a mass of gas at 1650 degrees F. (900 degrees C.) are unavailable for heating anything above 1650 degrees F. (900 degrees C.), no matter how many of them there may be. In other words, equilibrium in

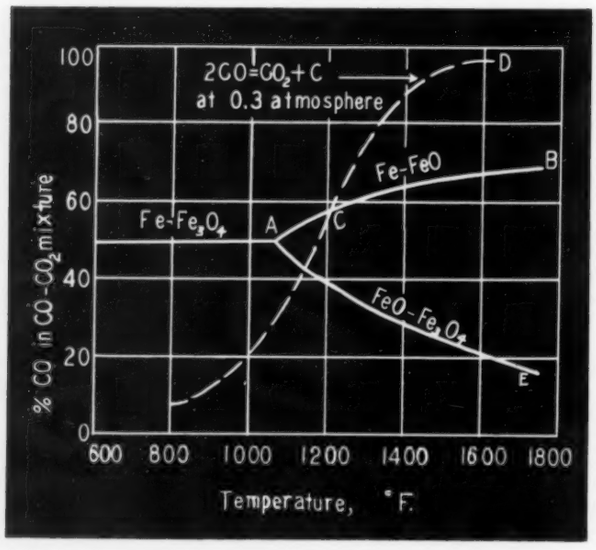
*The reader is reminded that in this paragraph only carbon required as reagent is considered, heat requirements being neglected for the moment.

this chemical reaction limits the extent to which we can utilize chemical energy just as the second law of thermodynamics limits the extent to which we can utilize thermal energy. As a consequence, 68 per cent of the carbon monoxide heated to 1650 degrees F. (900 degrees C.) remains unutilized in the reduction of ferrous oxide at that temperature; so that to utilize 32 per cent of our carbon monoxide we must heat 100 per cent, or over three times as much (100/32 = 3.1). A more appropriate picture of conditions at this temperature is therefore given if we write the equation

$$FeO + 3.1CO = Fe + CO_2 + 2.1CO, \text{ at}$$
$$1650 \text{ degrees F. (900 degrees C.)} \qquad [4]$$

Experiment also shows that there is an equilibrium mixture of carbon monoxide and carbon dioxide characteristic of the reduction of each of the three oxides of iron, that is, the reduction of Fe_2O_3 to Fe_3O_4, of Fe_3O_4 to FeO and of FeO to Fe, and that each of these equilibria varies with temperature. The equilibrium composition of the gas over each pair of solid reagents, as listed above, and at any temperature can therefore be represented by the diagram shown in Figure 1, in which the solid lines give the result of direct measurements. This diagram tells us that in order to produce iron and to keep it from being reoxidized, the final concentration of carbon monoxide in the gas must at a given temperature be greater than the equilibrium concentration shown for that temperature by the line *AB*. The minimum amount of carbon as CO required to produce a ton of iron is, therefore, that consumed in the actual reaction, as given by equation 3, plus that amount required to maintain the necessary excess of CO as indicated by Figure 1; in other words, at each temperature it is given by an equation similar to equation 4 for 900 degrees C. This result applied to an imaginary perfect furnace, working under equilibrium conditions throughout—that is, at equilibrium in the reduction and with perfect countercurrent operation in the rest of the process—enables us to set up a standard for the performance of an actual furnace, corresponding precisely to the Carnot cycle as the standard for the performance of a steam engine.

FIGURE 1—Equilibrium concentration of carbon monoxide in reduction of iron oxides (full lines) and in solution reaction (dashed line).



Let us imagine such a furnace as consisting of three chambers with connections for passing gas from one to another. In the first chamber Fe_2O_3 is reduced to Fe_3O_4, in the second Fe_3O_4 is reduced to FeO and in the third FeO is reduced to Fe. It is assumed that at the start each chamber contains enough oxide to yield a ton of iron, that all three chambers are at the same temperature, that the reducing gas contains only CO and CO_2, that all reduction is indirect—that is, effected by means of CO—and that there is no loss of material as flue dust. The restriction that the reducing gas contain only CO and CO_2 is entirely a matter of convenience because the presence of an inert gas such as nitrogen merely dilutes the active gases but does not change their ratio, which is the governing factor. The operation of such a furnace corresponds very closely with the ideal operation of Gruner in that all the reduction is indirect. It should also be emphasized that this perfect furnace in which the reduction takes place in steps is not intended to be a counterpart of an actual furnace, any more than the thermodynamic engine used to demonstrate the operation of a Carnot cycle need be a counterpart of a steam engine, but it is used because it permits us to carry out the reduction with carbon monoxide at maximum efficiency.

As the equilibrium concentration, hence the carbon consumption, varies with the temperature at which the perfect furnace operates, it is of interest to calculate the carbon required per ton of iron produced for several different temperatures, to learn the magnitude of the variation. Taking first the relatively low temperature of 1500 degrees F. (815 degrees C.), we shall consider the operation of the perfect furnace in detail, starting with the chamber in which FeO is reduced to iron because this step (Figure 1) requires the highest $CO:CO_2$ ratio. The line *AB* in Figure 1 shows that at this temperature only 36 per cent of the CO is effective for reduction, consequently there must be a total of 100/36 or 2.8 mols of CO and the process can be described by the equation:

$$FeO + 2.8CO = CO_2 + Fe + 1.8CO,$$
$$\text{for 1500 degrees F. (815 degrees C.)}$$

Thus, if we start with 2880 lb. of FeO, enough to give 2240 lb. of iron, a minimum of 1343 lb. of carbon is required, of which 480 lb. is for actual reaction and 863 lb. goes to maintain the indispensable excess of CO. Allowing for coke with 90 per cent fixed carbon, this represents a coke consumption of 1498 lb. per ton of iron, as the minimum necessary to furnish the chemical reagent or the amount required under perfect conditions at this temperature.

After the production of a ton of iron, the residual gas is transferred into the next chamber, which contains enough Fe_3O_4 to supply 2880 lb. of FeO. This residual gas contains 64 per cent CO, an amount that is considerably in excess of the equilibrium concentration of 28 per cent CO (curve *AE*, Figure 1) for this pair of oxides at the same temperature of 1500 degrees F. (815 degrees C.); consequently the gas can reduce Fe_3O_4 and continues to be reducing as long as the concentration of CO remains above that at equilibrium. As the

amount of carbon required for actual reaction in reducing Fe_3O_4 to FeO is only 159 lb. per ton of iron, and as the residual gas contains 863 lb. of carbon as carbon monoxide, the gas can supply all the carbon necessary for reduction without having the CO content fall below 52 per cent, which is nearly twice the equilibrium concentration, at which reaction would cease.

After complete reduction of the Fe_3O_4 to FeO, the residual gas is transferred to the first chamber which contains Fe_2O_3. As the gas at this stage contains 52 per cent carbon monoxide, which is many times the equilibrium concentration of CO in contact with Fe_2O_3 and Fe_3O_4, it reduces Fe_2O_3, and since it contains 704 lb. of carbon as carbon monoxide, it can supply the 80 lb. of carbon required for reduction without appreciably changing the $CO:CO_2$ ratio. It is evident therefore that a gas that contains enough carbon monoxide to reduce 2880 lb. of FeO to give 2240 lb. of iron under equilibrium conditions at this temperature contains more than enough CO to reduce an equivalent amount of Fe_3O_4 to FeO and of Fe_2O_3 to Fe_3O_4 as well.

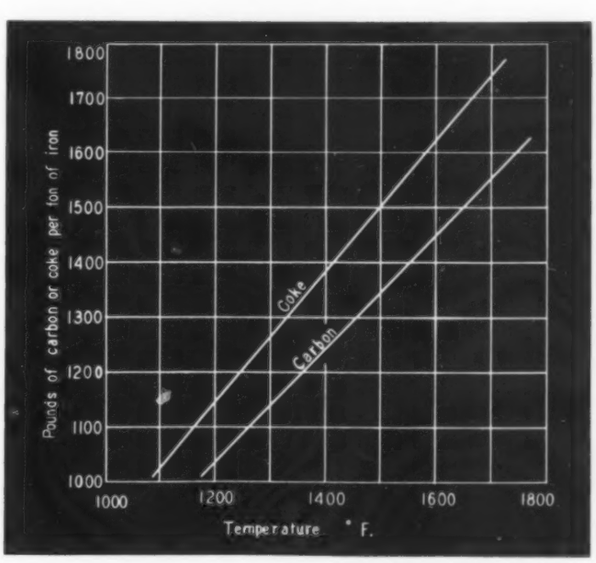
It should be noted that the total carbon required for actual reaction with oxides of iron in order to produce a ton of iron from Fe_2O_3 is 480 lb. for reduction of FeO to Fe + 160 lb. for reduction of Fe_3O_4 to FeO + 80 lb. for reduction of Fe_2O_3 to Fe_3O_4, or a total of 720 lb., which is just what was calculated from equations 1 and 2, whereas a minimum of 1343 lb. of carbon is needed at this temperature for the reactions described, which represent the most effective utilization possible of carbon in reduction of iron oxides to iron with CO. The difference of 623 lb. represents the excess carbon as carbon monoxide that is necessary to maintain a reducing atmosphere but is rejected at the end of the process. In practice this excess must be even greater than 623 lb. because it is necessary to have more CO than is required at equilibrium in order to have an appreciable rate of reduction.

Similar calculations at other temperatures show that throughout the temperature ranges likely to be found in the stock column the amount of carbon necessary to meet the equilibrium requirements in the reaction between ferrous oxide and carbon monoxide is also sufficient to carry out the earlier steps, the reduction of Fe_2O_3 to FeO. It is therefore not necessary to consider further the earlier steps and we may focus attention on the carbon requirement of the final step; that is, the production of metallic iron from FeO. Furthermore, this relation will, in general, hold for an actual blast furnace even though the reduction does not actually take place at a single temperature, so that we can with some confidence apply the conclusions drawn from the operation of the perfect furnace to an actual furnace, without making any assumptions as to reduction definite steps at definite temperature levels.

At a higher temperature—for example, 1800 degrees F. (980 degrees C.)—the equilibrium requirement for the reaction $FeO + CO = Fe + CO_2$ is somewhat less favorable and more carbon is required. A calculation similar to that just made shows that at this temperature the minimum requirement is 1636 lb. of carbon, or 1840 lb. of coke, on the basis that the coke contains 90 per cent fixed carbon. Calculations for other temperatures lead to the data shown by curves 1 and 2 in Figure 2; curve 1 giving the minimum amount of carbon required, curve 2 the corresponding amount of coke. It is assumed in each case, of course, that all the reduction is carried out by means of CO; consequently, these values correspond to the coke consumption under ideal operation as postulated by Gruner.

If, however, the operation of a furnace should be such that reduction is not complete in the stack and some appreciable amount occurs in the hearth zone by direct reaction between iron oxide and carbon, the coke consumption calculated to meet the requirements of the reducing reaction as to chemical reagents (i.e., not considering thermal requirements) might be lowered slightly below the values given in the figure. (A condition of this kind might result if the charge contains iron-bearing materials that for one reason or another, such as chemical constitution, density or particle size, are not readily reduced to metal by the furnace gases.) In this case, some of the reduction is effected under conditions approaching the oxide-slag iron-bath system previously mentioned, in which the carbon required is only 720 lb. per ton of iron produced. The magnitude of the saving in coke resulting from this condition can be estimated by taking a specific example. Assume that 95 per cent of the reduction is carried out by CO at an effective temperature of 1800 degrees F. (980 degrees C.) and 5 per cent is carried out by carbon in the hearth zone. The minimum amount of carbon required per ton of iron is $0.95 \times 1636 + 0.5 \times 732 = 1580$ lb., or nearly 60 lb. less than if the reduction is all by CO. Under certain circumstances, therefore, it is possible, by having a small amount of direct reduction, to operate more efficiently than by following Gruner's ideal procedure. It is clear, however, that this can be done only if the lessened amount of carbon required, together with the available hot-blast temperature, still suffices to supply the heat needed; that is, if the rate of coke consumption is governed by the use of carbon as a reagent rather than as fuel. Otherwise, a reduction in carbon will reduce the heat supply below the level necessary for con-

FIGURE 2—Temperature variation of amount of coke and carbon required by imaginary perfect blast furnace working under optimum conditions.



tinued operation. There are thus obvious practical limitations to having a large amount of direct reaction between carbon and iron oxide, mainly because of the substantially greater supply of heat required for this direct method of ore reduction as compared to indirect reduction by CO.

HEAT REQUIREMENTS

It now remains to see whether the amount of carbon required to provide the necessary reducing gas also suffices to supply the necessary heat. In considering this, we shall pass over for the moment the question of where this heat is produced and consider only the net heat generated in the furnace as a whole. According to the heat balance given by Mathesius, which is reproduced in Table 2, a blast furnace producing the common grades of pig iron requires approximately 13,000,000 Btu. for each ton of iron produced, of which close to 11,000,000 are commonly supplied by combustion of coke and the remaining 2,000,000 are brought in by the hot blast. If, therefore, the heat liberated by combustion of the coke required to give the necessary reducing gas is of the order of 11,000,000 Btu., or greater when the carbon is burned so as to give the equilibrium mixture of CO and CO_2, it may be concluded that the coke consumption is determined mainly by the use of carbon as a reducing agent. On the other hand, if the heat thus liberated is less than 11,000,000, and is so much less that it is not practical to supply the difference by increasing the heat brought in by the hot blast, it may be concluded that the coke consumption is fixed by heat requirements.

Although the temperature at which rate of reduction by CO becomes rapid varies considerably with the nature of the ore, it is not unreasonable to assume that 1500 degrees F. (815 degrees C.) is somewhere near the lowest temperature at which reduction can be carried on at a feasible rate. The data collected by S. P. Kinney show that not more than 20 per cent of reduced ore is present at the level for which the average temperature is 1500 degrees F. (815 degrees C.), and considering the rapid decrease in rate of reduction with decreasing temperature it is not likely that reduction is occurring very rapidly below this temperature. Even granting that 1500 degrees F. (815 degrees C.) is somewhat higher than the minimum temperature for an economical rate of reduction of FeO, no appreciable error is introduced into the calculations as made.

Now at 1500 degrees F. (815 degrees C.), each ton of iron produced requires, as we have seen, 1343 lb. of carbon, of which 480 lb. appears in the exit gas in the form of CO_2 and 863 lb. as CO. We may therefore consider the carbon as being in effect burned partly to CO_2 and partly to CO, so that the heat to be credited to combustion, using the same heats of combustion as Mathesius, is $480 \times 14450 + 863 \times 4453 = 10{,}820{,}000$

TABLE 2.—*Heat Balance Sheet for One Ton of Product*
TAKEN FROM MATHESIUS

Generated			Consumed			
By	Btu.	Per Cent	By	Btu.		Per Cent
Combustion C to CO	3,995,000	31.1	Reduction of Fe_2O_3	6,133,300		
Combustion C to CO_2	6,754,000	52.6	Reduction of Fe_3O_4	490,000	6,623,300	
			Reduction of MnO		48,400	
Hot blast (heat content)	2,057,000	16.0	Reduction of P_2O_5		17,000	
Moisture of the air in hot blast (heat content)	42,000	0.3	Reduction of SiO_2		418,500	7,107,200 55.3
			Calcination of carbonates			702,000 5.5
			Dissociation of moisture in blast			397,000 3.1
			Carried off with the iron			1,142,500 8.9
			Carried off with the slag			909,000 7.1
			Carried off with the dry top gases			752,400 5.9
			Carried off with moisture in top gas			700,100 5.4
			Radiation, cooling water, and unaccounted for			1,137,800 8.8
Total	12,848,000	100.0	Total			12,848,000 100.00

Btu., which is very close to the credit of 3,995,000 + 6,754,000 = 10,749,000 Btu. made in Table 2. At 1800 degrees F. (980 degrees C.) the carbon required is 1656 lb., of which 480 is in effect burned to CO_2 and 1176 lb. goes to CO, consequently the heat liberated is $480 \times 14450 + 1176 \times 4450 = 12{,}210{,}000$ Btu., which is considerably more than the credit for combustion in Table 2. It appears, therefore, that with reduction by CO the heat generated by combustion of the coke required to produce the reducing gas is very nearly enough to supply the heat needed in the furnace (using the raw materials and producing the grade of iron described) and that the hot blast, under most conditions, can supply enough heat to make up any deficit and maintain a satisfactory operating heat balance.

If there is some reduction by carbon in the hearth, the heat generated per unit of carbon charge and available for reactions above the hearth is somewhat less, but unless there is a very large amount of such reduction the heat evolved is not enough less to require any revision of this conclusion. Moreover, the calculations of the amount of carbon required as a source of reducing agent are based on the assumption that reduction is carried out with a gas of which the carbon monoxide content is substantially the same as that of the equilibrium mixture, when, consequently, the rate of reaction would be effectively zero. In order to have the reduction go on at an economically feasible rate it is necessary to have some excess of carbon monoxide over that required for equilibrium, hence the amount of carbon actually required for reduction is somewhat greater than that calculated for equilibrium conditions and there is a corresponding extra heat supply above that already taken into account. This means that the heat that has to be brought in by the hot blast is somewhat less than that calculated, and gives added assurance that the hot blast can supply the difference between the total heat requirement and the heat supplied by the combustion of carbon to form the actual CO-CO_2 mixture.

These conclusions are, of course, valid only for the production of the common grades of pig iron. If the furnace is making ferrosilicon or ferromanganese, the heat requirement is considerably greater than that given in Table 1, and in such cases the coke consumption may be fixed by the heat requirement rather than by the necessity of maintaining a reducing atmosphere. On the other hand, the amount required for reduction would likewise be greater, because the final CO:CO_2 ratio would have to be higher, possibly considerably higher; but the requisite basis of calculation for ferrosilicon and ferromanganese is still uncertain, and it would lead too far to discuss this here.

It should be noted in this connection that the heat of combustion of carbon to CO_2 (14,450 Btu. per lb.) is so much greater than the heat of combustion to CO (4453 Btu. per lb.) that a small change in the CO:CO_2 ratio of the combustion gases is accompanied by a relatively large change in the heat evolved. For example, one pound of carbon burned in such a way that the ratio of CO to CO_2 in the combustion gases is 2.0 liberates 7720 Btu., whereas only 7550 Btu. are liberated if the CO:CO_2 ratio is 2.2.

The relatively close agreement between the heat supplied on combustion by the carbon required to give the necessary excess of carbon monoxide and the heat required for the furnace as a whole shows that the final balance is obtained by means of blast-temperature regulation. It also indicates the high degree to which the management and operation of the blast furnace have been developed, for unless there is a proper selection of the charge, particularly of the fuel, a proper furnace design and proper operating practice, a proper rate of driving, for example, the difference between the heat requirements of hearth and stack zones is so great that a complete balance cannot be achieved by blast-temperature regulation alone. The fact that such regulation is possible is a tribute to the skill of the blast furnace operator.

Thus far, nothing has been said about the effect on the reduction equilibria of the presence of metals other than iron, such as manganese or silicon, or of metalloids such as phosphorus. Precise data bearing on this point are scarce but it seems likely that the effect of phosphorus and sulphur can be neglected because they are present at a relatively small concentration and that no great error is introduced if it is assumed that manganese acts as if it were iron. On the other hand, silica is generally present in appreciable quantities and has a high heat of reduction to silicon, so that it should be considered. Schenck and Laymann measured the equilibrium of CO and CO_2 over mixtures of iron, iron oxides and silica at 900 degrees C. (1650 degrees F.) with the following results. In the reduction of Fe_2O_3 to Fe_3O_4 and Fe_3O_4 to FeO, the equilibrium concentration of CO was slightly lower in the presence of silica than with the iron oxides alone. Equilibrium in the reduction of FeO to Fe appeared to be sensitive to the proportion of iron present; with a ratio of SiO_2 to Fe of 5 to 1 by weight, the equilibrium ratio of CO to CO_2 was approximately 5.6, which is considerably higher than that in the absence of SiO_2, whereas if the ratio of SiO_2 to Fe was 1 to 5 the equilibrium ratio of CO to CO_2 was identical with that over FeO and Fe alone. Moreover, no detectable reduction of silica occurred until an appreciable quantity of iron was present. These observations indicate then that if the ratio of Fe to SiO_2 is high, as it must be over a large portion of the lower part of the furnace, SiO_2 has little effect on the equilibrium in the reduction of FeO by CO. Such influence as there is, however, is in the direction of increased carbon consumption, and although we shall neglect it in this preliminary survey, it may well be that when more accurate data on blast-furnace operation are available and a more precise calculation is attempted the effect of silica will have to be taken into account. Schenck gives further data on the reduction of silica itself under blast-furnace conditions, which indicate that this reaction rakes place chiefly between silica as a component of molten slag and molten iron saturated with carbon, and that the final silicon content of the iron is determined chiefly by the temperature of the molten iron in the hearth and the composition of the slag. As a consequence the amount of carbon required to supply both the reagent and the heat necessary to reduce this silica is not a fixed amount but varies widely, and about the best that we can do is to assume that it is greater but of the same order of magnitude as that required to reduce an equivalent amount of iron.

It should be noted that as the hearth temperature is

effectively fixed by the composition of iron and the slag being produced, and as the hearth temperature is an important factor in determining the coke rate, there is a direct relation between the composition of the pig iron produced and the coke consumption.

This discussion has also neglected the 3 or 4 per cent of carbon contained in the molten pig iron, but this omission is largely compensated for by the fact that the preceding calculations are based on a ton of pure iron rather than on a ton of pig iron. For example, the carbon consumption for 1600 degrees F. (871 degrees C.) as given by curve 1 in Figure 2 is approximately 1450 lb. per ton of pure iron. The carbon consumption for a ton of pig iron containing 94 per cent iron and 4 per cent carbon is therefore $1450 \times 0.94 = 1363 + 2240 \times 0.04 = 89$, or a total of 1452 lb. of carbon, which is substantially the same as the requirement given by the curve for pure iron. When allowance is made for carbon required to reduce other oxides, such as SiO_2, MnO and P_2O_5, this consumption is slightly increased, but the values given in Figure 2 can be taken as a good first approximation when considering either a ton of pure iron or a ton of pig iron. It should be noted that these values are for iron actually reduced, and a furnace charging an appreciable quantity of scrap can obviously show a considerably lower consumption.

In pig-iron production we are thus justified in regarding the carbon consumption as set primarily by the amount required for reduction, and it is of interest to estimate what the efficiency of an actual furnace is on this basis. In making such an estimate the data in Figure 2 are useful and lead to some fairly definite conclusions. First, it is obvious that the higher the temperature at which the reduction is carried out, the higher is the coke consumption. It is therefore desirable from the standpoint of coke consumption to operate at as low a reduction temperature as other factors permit. Second, many modern blast furnaces are operating at a very high efficiency, as is evident if an approximate calculation of the efficiency is made on the basis of curve 2. Reduction in the blast furnace does not occur at a single temperature, and there is even a difference of opinion as to the temperature range in which most of the reduction does take place, but for the purpose of this calculation no great error is introduced if it is assumed that most of the reduction is carried out at a temperature of 1600 degrees F. (871 degrees C.), which is probably close to the mean temperature of the reduction zone. An appreciable fraction of the total reduction occurs above this temperature, and thus requires more coke per ton of iron than the part reduced at 1600 degrees F. (871 degrees C.). On the other hand, there can be no doubt that some reduction occurs below 1600 degrees F. (871 degrees C.) and as such low-temperature reduction requires less coke than is necessary at 1600 degrees F. (871 degrees C.) this tends to offset the larger amounts required in high-temperature operation. The temperature 1600 degrees F. (871 degrees C.) is therefore believed to be a fair basis for the estimate. Neglecting the possibility of direct reduction in the hearth, the minimum coke consumption as taken from Figure 2 is about 1600 lb. per ton of iron produced from ore. Consequently, a furnace using 1700 lb. of coke is operating at close to 95 per cent efficiency, and a furnace using 1800 lb. of coke is about 90 per cent efficient. If the furnace is operated in such a way that the reduction of FeO to Fe is carried out at a lower temperature, the coke consumed is correspondingly less, and the fact that a coke rate of 1460 lb. has been achieved in practice, although under rather special conditions, shows that such low-temperature reduction with a very high efficiency is possible, and that it is economical as far as coke consumption is concerned. It may not be economical, however, if one considers the output of the furnace and the return on the capital invested. These efficiencies, of course, are only estimates based on many assumptions, but as the assumptions are reasonable the conclusions based upon them can be used with some confidence.

It is also evident that the faster a furnace is driven the less chance there is for the attainment of equilibrium, or true countercurrent operation, hence the coke rate should, and in fact does (within reasonable practical limits), increase with the rate of production of iron. In striving to achieve most economical operation with a given furnace, it is therefore necessary to balance the rate of production against the cost of coke, which is an interesting problem but one that is outside the province of this discussion.

Furthermore, since the efficiency of modern furnaces is over 90 per cent, based on the performance of the perfect furnace, it is clear that the more complicated devices now being promoted by inventors have little, if any, chance of producing a spectacular reduction in the coke consumed per ton of iron. This, of course, does not mean that no improvement in blast-furnace practice is possible. On the contrary, it is safe to predict that advances can and will be made, but if the interpretation just given is correct the improvements will be more in the form of closer control to secure a more uniform product than in any marked reduction of coke consumption below that of the best practice at present. Summarizing these conclusions, we find: first that the ultimate lower limit of coke consumption for pig iron is in most cases determined by the chemical equilibrium of the reduction reactions, particularly by the equilibrium over FeO and Fe; second, that the carbon consumption decreases with the temperature of the reduction; consequently, greatest economy is obtained by carrying on the process at as low a temperature as is connected with a satisfactory over-all rate of production of iron. Finally, if our interpretation is correct, the relative efficiency of a modern blast furnace, defined as the ratio of coke consumed by the perfect furnace to that consumed in the furnace in question, is remarkably high. The exact value is difficult to estimate because in actual operation metal is produced not at a single temperature but over a range of several hundred degrees, but the indications are strong that many modern furnaces are operating at over 90 per cent of their maximum theoretically possible efficiency.

The relatively high efficiency indicated by the coke consumption implies that many furnaces are working rather close to equilibrium. Further evidence to support this deduction is found in the agreement between direct measurements made by Kinney of the gas composition at four different levels in the stock column of a commercial furnace and the $CO:CO_2$ ratio at equilibrium as calculated from Figure 1 and from the operation of the perfect furnace. This agreement is shown in

Table 3, in which the first column gives the position for which the data apply, expressed as distance from the wall at the given level, the second column gives the temperature at that point, as read from Kinney's curves, the third gives the ratio of CO to CO_2 as calculated from his data, and the fourth gives the equilibrium ratio of CO to CO_2 for the temperature given in the second column as calculated from the data of Figure 1. The gas composition is expressed as the ratio of CO to CO_2 rather than in percentage of CO or CO_2, for two reasons: (1) to emphasize that the important point is the value of this ratio; (2) to avoid any confusion resulting from the fact that the actual furnace gas contains a large percentage of nitrogen, which is without effect on the equilibrium.

At plane 4, the hottest level investigated, there was always excess of CO above that required for equilibrium over Fe and FeO, as, of course, there must be if rapid reduction to metallic iron is taking place. At plane 3, the observed ratio shows surprisingly good agreement with the equilibrium ratio over the whole distance investigated. It is true that the furnace gas contains slightly less CO than is required at equilibrium but in view of the difficulty in making observations and of the sensitivity of the ratio to small changes in composition in this range, the difference is not great and the data can be taken as indicating that at this level equilibrium had been substantially attained. At plane 2, the CO content is definitely below that required for equilibrium over FeO and Fe, but is appreciably above the CO concentration at equilibrium over Fe_3O_4 and FeO. This means that at this level the gas can reduce Fe_3O_4 but not FeO; indeed, it is oxidizing in relation to iron and will tend to convert any reduced metal back to ferrous oxide. The most interesting point about the data for this plane, and those for plane 1 as well, is that the ratio is constant at approximately 1.4, which corresponds in a mixture of pure CO and CO_2 to 58 per cent carbon monoxide, because it was shown in an earlier section that in the perfect furnace the CO content was not reduced below 52 per cent (or a ratio of 1.1). The exact concentration of CO remaining in the gas in an actual furnace obviously depends on the speed at which the gas passes over the ore, but the fact that the CO content of the gas in the furnace approaches that of the gas in the perfect furnace so closely indicates that equilibrium and true countercurrent operation in the stock column are likewise approached.

TABLE 3.—*Comparison of CO:CO_2 Ratio in Different Parts of a Blast Furnace*

AS REPORTED BY KINNEY WITH RATIO AT EQUILIBRIUM

Location Feet from Wall	Observed Temperature, Deg. F.	Observed Ratio of CO to CO_2	Equilibrium Ratio of CO to CO_2 (Fig. 1)	
			Over Fe -FeO	Over FeO -Fe_3O_4
PLANE 1 (6 FEET BELOW STOCK LINE)				
1	450	2.1		1.0
2	575	1.4		1.0
3	740	1.3		1.0
4	880	1.3		1.0
5	1040	1.4		1.0
6	1180	1.4		1.2
7	1300	1.7		1.5
8	1325	4.2		1.6
PLANE 2 (14 FEET BELOW STOCK LINE)				
1	1100	2.1	1.0	0.9
2	1000	1.4	1.0	1.0
3	1200	1.4	1.3	0.7
4	1550	1.4	2.3	0.3
5	1600	1.4	2.3	0.3
6	1625	1.4	2.3	0.2
7	1625	1.4	2.3	0.2
PLANE 3 (24 FEET 7 INCHES BELOW STOCK LINE)				
1	1575	1.9	2.0	
2	1375	1.3	1.7	
3	1625	1.8	2.2	
4	1650	1.8	2.3	
5	1650	1.8	2.3	
6	1650	2.0	2.3	
7	1700	2.2	2.3	
PLANE 4 (47 FEET BELOW STOCK LINE)				
1	1400	99.0	1.7	
2	1650	19.0	2.3	
3	1840	4.9	2.6	
4	1900	3.5	2.7	
5	1875	3.2	2.6	
6	1750	3.5	2.4	
7	1800	3.8	2.4	
8	1850	4.0	2.6	

We have thus far considered the operation of the perfect furnace and have rated the performance of an actual furnace in terms of the operation of the perfect furnace. It now becomes of interest to see how the operation of an actual furnace departs from that of the perfect furnace and to determine how departures from equilibrium and the occurrence of side reactions influence the efficiency. It has already been shown that the necessity of operating with an excess of carbon monoxide above the concentration of equilibrium in order to make the reaction proceed at a reasonably rapid rate leads to an increased consumption of carbon with consequently less efficiency. Failure to operate under true countercurrent flow, which is simply another way of saying that equilibrium is not attained, for true countercurrent flow implies equilibrium at every point

in the furnace, leads to an increased consumption of carbon. One of the commonest causes of deviation from countercurrent operation is the tendency for the reduced iron shell surrounding each lump of ore to sinter, thereby making it much more difficult, sometimes effectively impossible, for the reducing gas to reach the unreduced oxide core. Another cause for lower efficiency is the occurrence of side reactions, particularly the so-called solution reaction $CO_2 + C = 2CO$. This reaction has definite equilibrium just as do the oxide reduction, so that at each temperature there is a particular ratio of CO to CO_2 that is not altered by long contact with carbon. (The equilibrium ratio in this case is also influenced by the partial pressure of both CO and CO_2 but since this effect is small compared to that of temperature it is neglected here.) If the composition of the gases differs from this ratio, reaction occurs in such a way as to make the composition approach that at equilibrium. Equilibrium compositions as determined by experiment are given by the dashed line in Figure 1 and show that at temperatures above 1400 degrees F. (760 degrees C.) the percentage of CO that can exist over carbon is greater than that required for equilibrium over FeO and Fe. Consequently, if the composition of the gas lies within the range represented by the field *BCD*, FeO is reduced and CO_2 reacts with C to give CO. As the temperature increases this field widens so that the chance for loss of carbon by solution increases. Actually, the net result is controlled by the relative rates of the two reactions, whose magnitude it is not possible to predict. But it can be said that both rates increase with temperature and experience indicates that the rate of reaction of CO_2 and C increases somewhat faster than the rate of reduction, particularly at an iron surface, hence high temperatures lead to increased solution loss for two reasons: (1) because of unfavorable equilibrium conditions and (2) because of increased rate of reaction. On the other hand, as the gases cool, the equilibrium shifts so as to cause a deposition of carbon, but the rate also decreases so that the amount of carbon actually deposited depends on the relative rates of cooling the gases and of reaction.

The conclusions as to the role of equilibrium in blast-furnace operation also have a bearing on the advantages, if any, to be gained by oxygen enrichment of the blast. So far as coke consumption is concerned, these advantages appear to be small if the furnace is working close to equilibrium. As oxygen itself does not enter into the reduction reaction, it can have no effect on the equilibrium, consequently the performance of a furnace working close to equilibrium conditions cannot be improved by having a higher concentration of oxygen in the blast. The only way oxygen can affect the process is by providing a higher combustion temperature and by giving a better control of the hearth heat, but these adjustments can usually be made more simply by changing the blast temperature. If, however, the furnace were making ferromanganese or ferrosilicon, which require a high hearth temperature and a large heat supply, an oxygen-enriched blast would probably be helpful, if economically practicable.

There is also evidence indicating that oxygen is beneficial in a furnace with a high coke consumption; for example, Lennings, in a careful experimental study on a furnace of 50 to 60 tons of iron per day, found that when the coke consumption was 2000 to 2200 lb. per ton of iron it could be lowered 200 to 300 lb. by the use of an enriched blast although extra oxygen was of little value when the coke consumption was normally low. This last observation is just what would be expected, since the closer the approach to the minimum fuel consumption set by equilibrium the less will be the effect of changes in blast composition. It is difficult to avoid the conclusion that in a furnace using 2000 lb. or more of coke per ton of iron an equivalent reduction in coke rate can be made by correcting faulty phases of operation or by increased blast temperature rather than by adding oxygen to the blast.

THERMAL EFFICIENCY OF THE BLAST FURNACE AS A SMELTER

In considering the thermal efficiency of the blast furnace, it is difficult to set up standards as definite as for material efficiency. It is possible, however, to come to a definite conclusion on certain points pertaining to the calculation of thermal efficiency. For example, since the primary function of the furnace is to produce a highly reducing gas, it is not logical to charge the furnace with the full calorific value of the fuel, that is, with the heat evolved on complete combustion to CO_2—for the perfect furnace, it should be charged with the heat of combustion to CO, and for a real furnace, with the heat actually evolved. The efficiency based on charging the furnace with heat generated in the furnace plus the heat in the blast and crediting it with useful heat work done in the furnace, including sensible heat in molten iron and slag, is, according to Joseph, usually over 80 per cent; Mathesius' heat balance shows an efficiency of over 80 per cent for his furnace. This high efficiency is obtained because the blast furnace is a recuperator with relatively high transfer of heat from gas to stock. The only loss is in sensible heat in top gas and cooling water, and in radiation from the walls, which Marshall has shown to be small.

It should be noted that the blast furnace utilizing 80 per cent or more of the thermal energy supplied to and generated in it is a much more efficient piece of apparatus than, for instance, the open-hearth furnace, which has a thermal efficiency of the order of 20 per cent.

MATERIAL EFFICIENCY OF THE BLAST FURNACE AS A GAS PRODUCER

The purpose of the gas producer is to make a combustible gas high in carbon monoxide, by the incomplete combustion of carbon, therefore if we consider iron as a by-product we may look upon the blast furnace as essentially a large gas producer. The top gas leaving the furnace is the gas considered, because this is the gas that is used as fuel. The hearth of the blast furnace is a very efficient gas producer because the gas leaving it has substantially no CO_2, but this gas is not available for use outside the furnace. At first glance the funda-

mental chemical reaction of the producer appears to be

$$C + \tfrac{1}{2}O_2 = CO$$

but the composition of the gas—that is, the relative amount of CO and CO_2 produced—is actually determined by equilibrium in the reaction:

$$C + CO_2 = 2CO$$

This reaction is identical with the solution reaction of the blast furnace, so that the amount of CO obtained varies with temperature in the manner shown by the dashed curve in Figure 1. (As before, we shall neglect the effect of changes in partial pressure and shall assume that the process is carried out substantially at a partial pressure of one atmosphere.) This curve shows that the proportion of CO in gas from an ideal producer increases with the effective temperature of operation and approaches 100 per cent only at temperatures above 1800 degrees F. (or 1000 degrees C.). Therefore, in considering the efficiency of a blast furnace as a gas producer, we should base the calculation not upon complete conversion of carbon to CO but upon the maximum amount of CO yielded by the ideal gas producer at the temperature considered. The efficiency so obtained we shall call the relative efficiency. Now Figure 1 shows that at temperatures above 1450 degrees F. (790 degrees C.) the equilibrium concentration of CO for the producer reaction is greater than that for the reduction of FeO to Fe, which, as already said, is the controlling reaction in the blast furnace. This means that in this temperature range the blast furnace must in principle be less efficient in converting carbon to CO than the gas producer. The maximum efficiency of the ideal producer is entirely analogous to that of the Carnot cycle efficiency of a steam engine in that it tells us what the maximum yield will be for a given temperature of operation, and the relative efficiency of the blast furnace is then comparable with the efficiency of an engine operating on some cycle that is less efficient than that of the Carnot engine.

In order to obtain an idea of the magnitude of this relative efficiency, the yield of carbon monoxide per ton of carbon consumed has been calculated for the gas producer and for the blast furnace, making the reasonable assumptions that the controlling equilibrium in the blast furnace is that for the reaction $FeO + CO = Fe + CO_2$ and that both gas producer and blast furnace operate substantially at equilibrium. The results (Table 4) indicate that the blast furnace is in principle only about 70 per cent as efficient as the gas producer. It should be noted that as the temperature is lowered the relative efficiency of the blast furnace as a gas producer increases, and according to Figure 1 may exceed 100 per cent at temperatures below 1450 degrees F. (790 degrees C.). This means that if the process could be carried out at such a low temperature, which is, of course, neither desirable on other grounds nor economically feasible, the blast furnace would yield a better gas than the producer.

TABLE 4.—*Relative Efficiency of Blast Furnace as Gas Producer Based on Pounds of CO Produced per Ton of Carbon*

Temperature	CO per Ton, Lb.		Relative Efficiency, Per Cent
	Ideal Gas Producer	Ideal Blast Furnace	
1500° F. (810° C.)...	3735	3000	80
1650° F. (900° C.)...	4480	3170	71
1800° F. (980° C.)...	4600	3300	71

It should be noted that if equilibrium in the reduction reaction is not attained—that is if the gases contain more CO than the equilibrium requirement—the assumptions inherent in the calculation of the relative efficiency are not met and the apparent relative efficiency of the blast furnace as a gas producer may exceed 100 per cent. Moreover in any actual case it is possible though not likely that failure to attain equilibrium may give the blast furnace a higher efficiency than the gas producer operating at the same temperature.

The usefulness of the gas produced has a great deal to do with the economical operation of the furnace because the credit for gas burned in the stoves, soaking pits and elsewhere is considerable; furthermore, it is evident that any new process designed to compete with the present blast furnace must also have a high efficiency as a gas producer, a fact that frequently is overlooked by promoters of such schemes.

THERMAL EFFICIENCY OF BLAST FURNACE AS A GAS PRODUCER

The thermal economy of a gas producer in the sense of heat generated that is not lost by radiation in cooling water, etc., clearly depends entirely on the design and cannot be idealized as can the material efficiency. It is, however, customary to consider the thermal efficiency in terms of the calorific value of the gas produced, and on this view a comparison of gas producer and blast furnace can readily be made. The so-called cold-gas efficiency of the producer as ordinarily used is defined as the ratio of the calorific value of the gas produced per ton of carbon to the calorific value of the carbon itself. Since the calorific value of the gas depends on the proportion of CO present, which varies with temperature, the efficiency will vary with temperature. The calorific value of one ton of carbon is approximately 28,000,000 Btu., while the calorific value of CO is about 4500 Btu. per pound of CO. Taking the data of Table 1 for the CO produced per ton of carbon, the cold-gas efficiency of the ideal producer varies from about 60 per cent at 1470 degrees F. (800 degrees C.) to nearly 75 per cent at 1800 degrees F. (1000 degrees C.). The cold-gas efficiency of the ideal blast furnace based on the data

in Table 1 is approximately 70 per cent of that of the ideal gas producer and ranges from 42 per cent at 1470 degrees F. to 52 per cent at 1800 degrees F. (1000 degrees C.). The actual cold-gas efficiency of a blast furnace based on flue-gas analyses is usually within the range given and indicates, as did the material efficiency, that the blast furnace is working close to maximum possible efficiency.

It is also of interest to consider the hot-gas efficiency of the gas producer, which Hirshfeld and Barnard define as the sum of the calorific value of the gas and the sensible heat of the exit gases divided by the calorific value of the fuel used, or:

$$\text{Hot gas efficiency} = \frac{\text{calorific value of gas} + (\text{heat generated} - \text{losses})}{\text{calorific value of fuel}}$$

Obviously, the only inefficiency here is the heat lost by radiation, in cooling water, etc., and since this is only a fraction of the heat generated in the producer its value will not be large. Furthermore, equilibrium does not enter into this calculation because the loss in calorific value of the gas through presence of CO_2 is exactly balanced by heat liberated in the furnace through reaction combustion to CO_2. Hirshfeld and Barnard, assuming that 20 per cent of the heat generated on the process is lost by radiation, etc., found the hot-gas efficiency of a gas producer to be about 94 per cent. The blast furnace will not quite achieve so high a figure because of loss of heat in the molten iron but its efficiency should be very close to 90 per cent. It should be noted, however, that this efficiency implies recovery of the sensible heat in the waste gases—a process that is done by the blast furnace chiefly in the furnace itself, whereas the gas producer frequently requires some other equipment to utilize this energy.

SUMMARY

A consideration of the material and thermal efficiencies of the blast furnace considered both as a smelter and as a gas producer leads to the following conclusions:

1. In a blast furnace producing the usual grades of low-silicon pig iron, the coke consumption is determined by the demand for carbon as a reducing agent rather than the demand for fuel, for the heat liberated on combustion by the carbon necessary to give the proper quantity of reducing gas, is, together with the heat brought in by the hot blast, sufficient to meet the heat requirements of the furnace. The general heat balance as well as the distribution of the heat generated between hearth (melting) and shaft (reducing) zones is controlled within limits by adjusting the temperature and volume of the hot blast. If the furnace is producing high-silicon foundry iron, ferromanganese or ferrosilicon, the heat requirement per ton of product is considerably greater than for the ordinary pig-iron grades and the coke consumption may be fixed primarily by the demand for carbon as fuel, although this may not always be true since the CO:CO_2 ratio at equilibrium is also raised in such cases.

2. The amount of coke required for giving a proper reducing gas is fixed chiefly by the equilibrium conditions in the reduction of FeO to Fe, and, since the equilibrium changes with temperature, the coke consumption is likewise influenced. The higher the temperature at which this stage in the reduction is carried out, the higher the coke consumption.

3. Preliminary calculations taking account of the chemical equilibrium indicate that a blast furnace using 1800 lb. of coke per ton of pig is over 90 per cent efficient in the utilization of coke.

4. The thermal efficiency of the blast furnace taken as a smelter is high, being usually better than 80 per cent.

5. Taking the blast furnace as a gas producer, the maximum conversion of coke to carbon monoxide must be less than that of a gas producer, the relative efficiency being in the ideal case about 70 per cent. An actual blast furnace usually operates close to its own ideal efficiency as a producer, however.

6. The hot-gas efficiency of the blast furnace regarded as a gas producer is high, being of the order of magnitude of 90 per cent.

7. These conclusions all indicate that the blast furnace as now operated is a relatively efficient apparatus compared to other chemical or metallurgical equipment. While improvements in design, in control of operation to give a uniform product, and in reducing heat loss by radiation and conduction are to be expected, there is little hope of making a substantial reduction in coke consumption under that achieved by the best modern practice. It is also clear that any process designed to compete with the blast furnace must, like the blast furnace, show a high efficiency both as a smelter and as a gas producer if it is to have any chance of success in competition with the blast furnace in the steel-producing districts, where metallurgical fuel, suitable for blast-furnace use, is commercially available.

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PLANNED MAINTENANCE *and the* MAINTENANCE BUDGET

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▲ IN discussing a subject as broad as this, and especially in times like this, I believe it is necessary for us to analyze our problems most carefully and exchange opinions with others. It is helpful to check back on the history of what has been the outcome of such discussions, and what organizations such as the Association of Iron and Steel Engineers have accomplished by them. It is outstanding that through discussion and the exchange of ideas by all kinds of engineering societies, research societies, personnel societies, cost accountants' organizations and others, remarkable accomplishments have been realized over a period of years in many lines of activity.

It was stated by James G. Harbord in his address before the A. S. M. E., Dec. 7, 1933—"The average rate of expenditures for renewal parts and maintenance in normal years is $4,800,000,000 in America". Today we have facts that the annual expenditures for replacement parts and maintenance, in normal years, is approximately $5,250,000,000, employing 6,500,000 to 7,000,000 men. Of this amount approximately $1,250,000,000 is on electrical apparatus and its application, employing 2,000,000 to 2,500,000 men.

It was only a few years ago that the maintenance division of any city, company or corporation was looked upon only as an expense department and today it is being readily seen that it is one of the major saving departments. Any company's maintenance department will naturally depend on the size of the plant, its location and the product which it manufactures. This also applies to our towns and cities, with their public works department and maintenance division and we should not forget the large buildings, bridges and dams which are being erected today.

I am merely mentioning these as it is becoming very outstanding that our industrialists through our different engineering societies, chambers of commerce, boards of trade, educational institutions, etc., are beginning to take more of an interest and know more about our city maintenance, what becomes of our tax dollars and how they are being spent. It is through our management organizations that the matter of budgets and costs and what is becoming of our dollars is being analyzed more carefully and being better controlled. People and society are demanding better and finer things every day; this is in line with our advancing educational system and is as it should be.

Show me a concern with a good maintenance department and I will show you a company that makes

E. C. BRANDT

money, with a good plant, a better place in which to work and better workmen to produce a better product. Show me a company with run down buildings and equipment, dirty shop and a group of workmen who are negligent and I will show you a failure or one which will fail. I will show you a company that our bankers are not interested in and consider a poor financial risk.

Show me a city with good public works and a maintenance department and I will show you a city that has good homes, better people, with better industries and more luxuries. They will raise better children and you will see a city where people and industries will want to locate.

Today we are building finer factories, larger buildings, installing better equipment, have better workmen, pay higher wages and in fact are doing greater things in the promotion of American society and the general welfare of our populace as a whole.

Our laws are being built around just such a set-up and everything pertaining to the betterment of humanity is being promoted and realized. Safety laws have been passed, zoning laws are being enforced, fire rules and regulations are being enforced everywhere. Our compensation laws are being enforced and with this in mind everything possible is being done to curtail accidents and a full realization of the safety of our people is being promoted.

I cannot appreciate any management who will neglect to properly maintain all of their properties and equipment nor any cities who are not properly maintaining their highways, bridges, sewers, streets, etc., and it is no longer a case where men can neglect these and permit a dangerous hazard to endanger the life and general welfare of its people.

With larger buildings and better equipment being installed one of the main items and consideration which is being analyzed now, is, what kind of maintenance will this property and equipment require? What will be the actual cost of this maintenance? This cost must be figured in the cost of the product and if maintenance is neglected, true costs are neglected and eventually larger bills and higher costs result. Therefore, as mentioned before, the maintenance department is no longer the expense department, but is the cost saving department.

Let us take our own personal properties as an example—our homes and our automobiles. If we do not keep our house painted, deterioration will take place and cost of repair will occur. Very few of us care to drive our car if it is defective. Therefore, we have it repaired and maintained to our comfort and the safety which is required by laws—if we don't, we will pay more.

Having been responsible for a large industrial plant's maintenance for a number of years, naturally, I have formed some very concrete opinions as to what our maintenance department was and what their responsibilities are. I feel that nothing should be left undone to accomplish the things expected of us.

A maintenance inspection division in my judgment is an important group in any maintenance set-up, as their main duty and thought is the prevention of maintenance. These inspectors are specialists in their particular line and it is their job to carefully inspect the buildings, light, heat and power facilities in every detail, including cranes, elevators, hoists, railroads, handling facilities, plant transportation equipment and everything that must be maintained.

When any deterioration is noted it is the inspector's duty to report this situation and see to it that the proper maintenance is made as early as possible and in this way the major expense of complete rebuilding or high maintenance costs are prevented. I am quite sure that with the installation of a maintenance inspection department, maintenance expense can be brought to a minimum. This is cost reduction.

A works engineering department which has charge of plant planning and layouts, new building projects, architectural work, installation of all equipments, including both mechanical and electrical equipment, test floors, etc., knows definitely what is going into every new building, how it is being installed and what maintenance will be expected in a few years. This department knows if new projects are not properly installed and if extraordinary maintenance will occur.

Another outstanding item which is set-up through a works engineering department is the adoption of standards and through this medium the minimum number of maintenance and renewal parts are brought about and naturally lower costs.

The superintendent of a maintenance division should make out a look-ahead budget and this should be reviewed annually for an appropriation which will be reviewed by the management and submitted to the executive organization for approval. I believe the responsibility of a maintenance department can be very readily summed up in saying that it is its job to keep everything in good repair, first class operating condition, see that good housekeeping is maintained throughout the entire plant and that large maintenance bills are not necessary. Also that the greatest economies are realized by constantly keeping after repairs of a minor nature.

A complete record should be kept of maintenance costs and maintenance superintendents must continue to make recommendations for replacement of the different units of equipment which they feel are inadequate and on which the maintenance costs are considered too high.

It is also the maintenance superintendent's duty to know of the latest and best equipments which are offered for different purposes and to make recommendations to the management and the production superintendents along this line. Maintenance costs play a large part in the rehabilitation and replacement program.

Most companies believe in good buildings, good equipment, good workmen and a good product. When good housekeeping and modern facilities are provided and a good place for our men to work, then we consider it a pleasure to show our many customers and friends our factories—their condition and what we are doing in them.

At this particular time, due to the economic conditions of not only the United States, but the entire world, this subject is very appropriate and I think worthy of not only this Association's consideration and discussion, but for all American industries.

The facts which present themselves are the necessity for better maintenance on everything we own and possess. As I travel throughout the country there is out-

standing evidence of the courage men have had in establishing the wonderful buildings, railroads, factories, bridges, highways, automobiles and all of the finer things of life to which the American people are entitled through the evolution of materials, scientific developments, engineering progress and fulfillment of demands and wants of the higher and ever increasing educated people.

It is therefore, a fact that we not only appropriate money for capital accounts and constructing all of these mammoth projects, but realize that sooner or later we must provide expense money for their maintenance to minimize the deterioration and erosion which is bound to occur with everything that exists.

However, scientific developments of materials have increased their wear and life to such an extent that past costs of maintenance in everything cannot be very well used as the standard for the present or a look ahead for the future.

When we consider the courage that many of us have had in establishing all of these things, we wonder where our courage now lies in the maintenance and continuance of these things which we all enjoy and which are a necessity for the subsistence of life and the hope of continuing prosperity and advancement.

During the last 20 years we have not only educated ourselves, but, we are now educating our children with more stringent educational laws, making it compulsory that each child go to school. Through this art we have been trained and educated to want and keep on wanting the finer things of life until we obtain them.

I am not willing to admit, although we are coming out of the worst readjustment period we have ever been in as a nation and as a world, that we have lost our courage, but, as I see the situation we are taking a complete inventory of our entire conditions and can only hope to come out of this readjustment period a better nation, with better facilities, better maintenance, better education and as a whole a nation looking forward to better times and prosperity.

I believe that America will have to be rehabilitated and the things we now possess repaired and properly maintained before other expansion will be made or is a necessity. Since we have all had the matter of expenses so embedded in our minds by our past several years' experiences, rehabilitation and maintenance is one of the main subjects of the day, not only from our government's standpoint, our corporation's standpoint, factories, railroads, etc., but our homes. America while standing idle the past few years has been wearing out. Therefore, financial budgets on the most economical maintenance program are in order.

All of the things which we possess have been built and constructed on capital accounts and the maintenance of all of these possessions will be rebuilt and maintained on expense accounts. With the guard which has been placed upon this type of expenditure by private enterprises it is going to require the best that is in all of us to have it realized.

I am not going to burden you with a lot of figures and statistics along the lines of budgets for maintenance operations as I do not know of any set of figures or tabulations which would suit each and every property's singular condition and the deviations which control or establish the amounts of money required for each property or facility is different according to the following:

What is the age of the present existing facilities?

What is the type of structure of the present buildings?

How have the present buildings and facilities been maintained in the past?

What grade of materials and workmanship were used when they were originally constructed?

What has been developed and produced for a greater output along manufacturing facility lines to obtain lower costs and better manufacturing conditions?

What has the immediate future to offer for the same equipment for producing at a lower cost?

What competition is to be met in the location where your present facilities are in existence?

Are your facilities capable of meeting lower costs and competition?

All of these things must be very thoroughly analyzed and the proper people come to a common conclusion as to what is the best procedure for establishing a budget for such maintenance and rehabilitation and carefully analyze and look into the future.

I have never seen a cost that was too low. Every cost is too high. We have heard from our managers, engineers, economists, sales managers and our customers that the costs must be reduced and I do not know of anything that we have all worked harder on and we will have to continue to work hard on, than to continue to reduce not only manufacturing costs, but, maintenance costs. In my experience the best way to arrive at the best cost, with the facilities at hand is to establish a budget or something to definitely shoot at, and this is the main object in establishing and having a budget of any kind.

I am one of the last men who would ever want to take away the initiative of any man or any company, but I do believe that history must be our best teacher. We have had depressions before and we are going to have them again and from history we must learn to provide ways and means to make them less severe each time they occur.

I also believe that certain readjustment periods are a healthy condition as they not only give each of us a chance to take an inventory of ourselves, but to take an inventory of our business, an inventory of the future and analyze our conditions as to general structure and stability for continuance.

While these inventories are being taken, ways and means could be provided whereby they could be termed rehabilitation periods instead of depressions and panics. As I see this overall situation this can only be accomplished through stabilization and control of finance, through equalization budgets and the establishing of equalization reserve accounts.

I do not know any more substantial organization to lay this problem before than our educational institutions, nor do I know anything more critical to the progress of any industrial nation than to see one industry after another having two or three months of poor business and having to close up shop, negotiate loans, and find themselves in a bad way because the control of finance has not been properly administered or managed.

It might be well for us as individuals to take some recognition of how, through our own personal efforts, the efforts of our outstanding insurance societies, pro-

motion of pension funds, etc., which provide for a rainy day, this same practical principal may be applied to the operation of our business. We would then have the material things for the continuance of our operations on a somewhat lesser scale, thereby eliminating the unemployment, suffering of humanity, and local and national welfares.

Why is it not possible to establish equalization budgets and equalization reserve accounts for rehabilitation purposes during slack periods? In my judgment this can be taken care of by establishing a small percentage to the accounts coming under maintenance of land, buildings, and building equipment and maintenance of machinery, tools and fixtures which are the things that wear out rapidly during the peaks of production and which we know will eventually have to be replaced the same as they have been replaced in the past. However, for some reason or other when demand of products are the highest, expansion, over production and over expansion has been made and when business falls off from the regular line of manufactured product our expenses are not curtailed accordingly.

Therefore, I believe that an equalization reserve account is in order for every progressive manufacturing establishment and if this could be put across nationally then we would welcome readjustment periods whereby our facilities could be rehabilitated and not look forward to them with sudden dread and disaster to our nation. This can only be done by managers establishing such reserves and then sticking strictly to the purpose for which this money was provided and not use this reserve for taking care of other unforeseen financial conditions.

There will be periods when some industries will need financial help and with all their facilities, such as buildings, grounds, manufacturing equipment, etc., in good operating condition will be more inviting for our bankers to review and will create a greater possibility for securing the financial aid which they may require.

If our buildings, grounds and manufacturing equipment are in a run down, poorly kept and worn out condition we cannot expect the sympathy of our bankers, and the possibilities are that they will not be interested in supporting our financial requirements.

There are many American industries producing seasonable products. Where this occurs you will find a successful management of this type operating their facilities at full capacity during these periods and providing rehabilitation money for maintenance of equipment and putting their plant in good condition for the next season's output. For example, automobile plants, canneries, furnaces, steel, glass, etc.

I cannot see any other principal that is as sound for our overall situation and in looking over our American industrial activity chart since 1854 I find that we have had approximately 18 periods of prosperity or those periods above normal and approximately 16 periods of depression or those periods below normal. The years of prosperity have varied from 1 to 5 years while the periods of depression have varied from 1 to 8 years.

The first thing we notice is that inquiries for quoting on our product have slackened somewhat, we notice that orders are not developing, we notice that manufacturing is letting up somewhat, we notice that our stocks and inventories are rising somewhat, and there is an indication that buying has ceased.

We wonder if we are getting into a slackening up period, some men may start to ask if we are getting into another depression. Others are more optimistic and say this is only a little lull in our own particular business, but we must remember that there are thousands of manufacturers who may be experiencing this same thing.

We immediately start to inquire of our sales and field service men what is occurring, most of them say that it doesn't amount to much, except that this customer and that customer have held up buying just temporarily, and that the salesman has not actually lost the business, but he expects to close the deal in a few days or a few weeks. These few weeks go by and the business is still not closed and the same story repeats itself. This hapens in many territories and a few more lines of business and continues to occur for six months or a year and we find ourselves in a below normal period.

History shows us in the past from these kind of occurrences we have developed into depressions from many angles and then management begins to wonder what to do on account of the volume variance which their particular line is realizing.

The possibilities of establishing equalization budgets whereby we would maintain our organization and keep operating by spending some of the surplus created for readjustment periods, are evident. It is obvious that this would curtail any severe reductions, layoffs, unemployment, etc., and we would have money available to continue purchasing; our men would still be earning money and continuing to purchase in this way the volume variance would be held to a minimum.

This process must be accepted nationally and if one company's volume variance after another continues, then there is only one thing to expect and that is the below normal period and the possibilities of drifting into some kind of a depression.

In the control of manufacturing expenses with volume variance it is absolutely necessary that we take all of the mentioned expense accounts and know approximately what percentage of our manufacturing cost each one of these expenses should be at normal production periods, and maintain these same ratios with our volume variance.

This should be recognized and realized by management and will continue down the line of its entire supervisory organization, and to me means one of the greatest instruments to management in preventing everyone becoming panicky, providing the necessary accounts and facts for scientifically managing any business.

It provides the instrument whereby expenses are adjusted gradually to meet declining volume. It also provides the instrument for gradually increasing volume. It gives the supervisory forces not only the ratio of expenses to manufacturing cost, but gives them the information that management wants them to have so they can become a more important factor in management.

Remember at this point that the foreman or divisional supervisor down the line who is not becoming a better man every day, knowing more about his costs and expense control will not be good enough to supervise

America tomorrow. Nor will this type of supervisor be able to replace the men higher up, who are learning how to control and prevent depressions and below normal manufacturing periods.

Taking all of the expense items as given you, herewith, they should be tabulated in numerical order and following this should be listed the normal amount of expense for each item for any particular class of manufacturing or business. This should be pro-rated on a percentage basis as to the percentage of volume variance of the business and in the chart I have started at 30 per cent and gone to 100 per cent laying out the definite dollar and cents which would be permissible with a certain volume variance.

You will note, however, that some of these accounts, such as accounts No. 1 and No. 2, general factory supervision, are not readjusted even though 30 to 100 per cent volume is available, as this group of managers can manage 100 men or 5,000 men.

However, this does not hold true with all classes of these expenses and you will note that a great many of the other accounts vary in a certain percentage with the per cent of activity, depending absolutely on the analysis or the kind of business which is being charted.

These figures and tabulations are only given to more clearly lay out this type of expense control with volume variance. The greater detail in which factory expenses can be laid out, in the name of the expense, with the coordinating number and broken down into different divisions or costing centers, the greater benefit will be derived, as it places the expense control versus volume variance under the supervisors who are directly responsible for incurring the expense.

You will note a percentage of these accounts maintains certain salaries and fixed expenses at 30 per cent of activity and when any business drops below that 30 per cent point that business is evidently in a depression condition and it warrants a reduction of salaries, demotion of supervisory forces, and what we term drastic action in our industrial financial control.

I am in hopes that America has learned enough from history of the past panics and will take advantage of finance and expense control in the future to prevent business as a whole from dropping to 30 per cent of normal. I am in hopes that it will never drop below 65 to 70 per cent which is enough fluctuation to satisfy most anyone. If we can maintain 75 per cent of normal and only fluctuate 25 per cent from normal we would be one of the most successful industrial nations and would have one of the most wonderful conditions that we could desire.

Of course I realize to ever obtain such proportions, a great many things which are not being controlled, would have to be controlled. This is especially true when we stop to think of the number of businesses which are practically closed during this present readjustment period and a great many of us may be asking ourselves—is it on account of over production, too many people in the same business, a supply greater than the demand, inefficient management and many other reasons, but as time goes on we must study and work hard to prevent such things recurring.

I, as an individual, could not hope to be persuasive enough to put such a program across nationally, but I do hope that I am submitting something that is sound

TABLE 1—OPERATING EXPENSES

Tabulation of Allowable Expenses vs. Volume Variance

Account	Per Cent of Activity							
	30%	40%	50%	60%	70%	80%	90%	100%
1. General factory supervision—Monthly	$ 600	$ 600	$ 600	$ 600	$ 600	$ 600	$ 600	$ 600
2. Superintendent and general foreman	400	400	600	750	750	750	750	750
3. Foreman and assistants	800	1200	1600	1800	2000	2000	2000	2000
4. Time study men	400	600	800	800	800	1000	1000	1000
5. Inspectors	800	1200	1600	1800	2000	2000	2000	2000
6. Clerical labor	400	800	1200	1600	1700	1800	2000	2000
7. Other expense labor	400	500	600	700	800	900	1000	1000
8. Shop supplies	100	150	200	250	300	350	400	400
9. Shop losses	50	50	60	70	80	90	100	110
10. Rendered service	1000	1000	1200	1200	1400	1400	1600	1600
11. Miscellaneous factory expense	2000	2000	2000	4000	4000	4000	5000	5000
12. Fixed charges	5000	5000	5000	5500	5500	5500	6000	6000
*13. Maintenance of land, bldg. and equipment	4000	4000	4000	4000	4000	4500	5000	5000
*14. Maintenance of machinery, tools and fixtures	8000	8000	8000	8000	8000	8500	8500	9000

*Money provided in equalization budget as described.

Under 50% production load is the most economical maintenance period or while shop is half idle on production.

and economical for your Association whereby it will be an instrument of management and control in times of economic distress and an effective control of maintenance expenses with volume variance.

Accounting for Maintenance Equalization Program

General—It is the purpose of the maintenance equalization program to standardize, over a period of say ten years, the amount of extraordinary maintenance expense budgeted in the indirect manufacturing expense rates and to make charges to current operations consistent with the productive activity for the period.

Limitations of Plan—The maintenance equalization program applies to extraordinary repairs to buildings and structures and the complete overhauling and rehabilitation of durable equipment.

Basis of Accrual—At each works, accrual rates shall be determined by listing specific items of expense to be included in the program. The period of accrual of recurrence for each individual item shall be determined. The normal monthly accrual for each item shall be obtained by dividing the amount of expense estimated for that item by the accrual period in months. The total normal monthly accrual shall be computed by summarizing the accruals for the individual items.

Budgeting Accrual—Accrual for maintenance equalization shall be budgeted in direct manufacturing expense identified to a special account, provision for maintenance equalization, and included in indirect manufacturing expense.

Where the maintenance of buildings and structures is supervised by a central maintenance department, the items covered by this account shall be budgeted and identified as general plant expense. In all other cases the accrual for buildings and structures shall be budgeted as a divisional or departmental expense as the case may be.

The accrual for complete overhaul and rehabilitation of durable equipment shall be budgeted in plant, divisional or departmental expenses depending upon the method of budgetary control used.

Credits to the Reserve—The amount of the monthly accrual shall be computed by multiplying the normal accrual rate by the current monthly activity per cent based on normal operations, or the exact amount of maintenance equalization cleared in cost may be determined by other means. Use of either of these alternates will depend on the cost system now in effect in your plant. Indirect manufacturing expense account shall be charged with the total accrual developed for the period, and the reserve account for maintenance equalization, shall be credited with the exact amount charged to indirect manufacturing expense.

Charges to the Reserve—Charges to maintenance equalization reserve account shall be initiated by expense orders identified to the maintenance equalization program. Care shall be exercised in assigning maintenance equalization expense order numbers to avoid charging items of expense to the reserve account which have not been included in the maintenance equalization program.

Addition or Cancellation of Items—The maintenance equalization program shall be subject to review at the time of each budget revision. Additions to, discontinuance of, or modification in items included in the accrual shall be made at that time. Balances in the reserve accrued by discontinued items shall remain in the reserve or at the discretion of the comptroller, may be restored to operations by crediting indirect manufacturing expense account originally charged.

Included in the Annual Appropriation—All expenditures anticipated during the coming year, chargeable to the maintenance equalization program shall be included in the annual appropriation request. At the time of submitting the request for the annual appropriation the estimated balance in the accrual account for the fiscal year and the anticipated accrual for the following year shall be reported with the appropriation request to the executive in charge of that unit.

DISCUSSION

PRESENTED BY

L. F. COFFIN, Superintendent Mechanical Department, Bethlehem Steel Company, Sparrows Point, Maryland.

T. E. HUGHES, Superintendent Maintenance Department, Carnegie-Illinois Steel Corporation, Duquesne, Pennsylvania.

JAMES FARRINGTON, Electrical Superintendent, Wheeling Steel Corporation, Steubenville, Ohio.

G. R. CARROLL, Assistant Maintenance Superintendent, Jones and Laughlin Steel Corporation, Aliquippa, Pennsylvania.

L. F. COFFIN: An effective maintenance equalization program such as outlined by Mr. Brandt, should appeal to those who have the best interests of both men and management at heart. Many progressive companies now follow in some measure, such a program.

The maintenance of buildings and structures, however, especially in corrosive atmospheric conditions, bears little relation to the rate of operation. In fact it appears in many instances, that deterioration is more rapid with lower rates of operation. This problem requires an annual survey and the assignment of funds to maintain these structures in this condition, regardless of rates of operation, if the ultimate lowest total cost of maintenance is to be realized.

Major and unusual jobs such as relinings, improvements, major repairs are best and most economically done during slack periods and all must agree that a program that provides for this will find the plant better able to take care of business when it comes and also provide more work for its men during the slack period.

T. E. HUGHES: The subject of Mr. Brandt's paper is probably the most important subject that maintenance men have to deal with today. I do not feel that Mr. Brandt's proposal is 100 per cent correct for maintenance problems in the steel industry, but I am inclined to agree with its major phases.

It seems to me that the application of any plan which will provide for general repair and rehabilitation work during periods of reduced plant operations or complete shutdown periods, should result in worthwhile economies because of the fact that any major job can be completed in considerably less time and, in addition, the men concerned can do their work more efficiently when their jobs can be planned and carried on without the handicap of potential hazards and delays that exist when the mills are operating to capacity.

In connection with funds, I am wondering, if such a fund as Mr. Brandt mentioned were established, what the present tendency would be toward taxing such accounts.

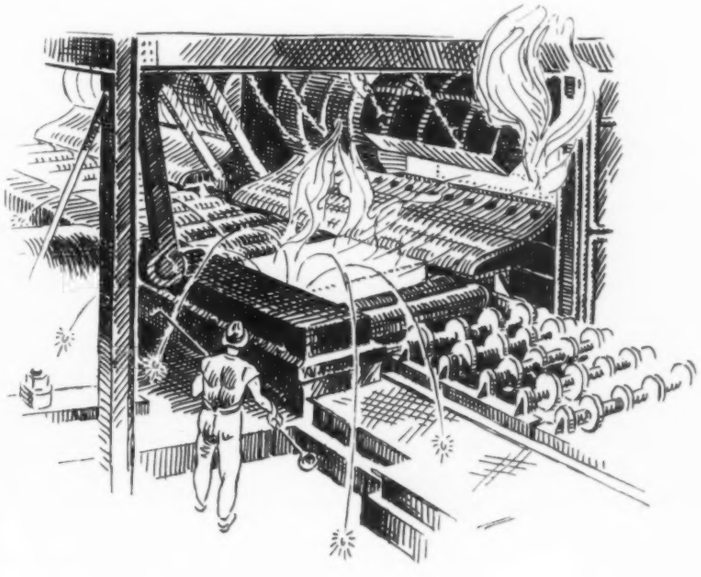
JAMES FARRINGTON: This is a subject that we have all wrestled with many years. Going back twenty-five years, many of you remember when even the superintendents of departments were not shown their costs, to say nothing of the foreman or men under them. For that reason most of the men did not know what their costs were and were not in a position to offer suggestions as to economical ways of repairing damage to equipment. Those costs have been given to us because they are of vital interest and are the basis on which every effort is made to lower costs.

In the open hearth there are certain reserves set up for furnace renewals because our executives realize that these renewals and repairs have got to be made but when you bring up to them a proposition to set aside a certain amount of money for repairs you feel reasonably sure are going to occur, they bring up the question, "Is it actually necessary and can we reconcile our stockholders if we set aside money for potential repairs out of surpluses or dividends?" However, our managements are generally in accord and sometimes executives can be convinced if they but realize your maintenance costs can be very materially increased if not taken care of at the proper time, and I believe a system can be set up whereby we can put aside in one quarter money to be spent in the next quarter, because neglected repairs raise the costs of the department. When a superintendent who keeps after his costs receives a cost sheet, he will see that it is fine for two or three months, and then when an extraordinary repair job has to be done, he gets a letter from the management asking about the increased cost. I believe as our executives realize the effect this will have on our actual reduction in maintenance, that we will in the near future be granted a certain amount to be set aside for that purpose, as it will be proven that is the most economical way to take care of our maintenance cost.

G. R. CARROLL: The matter of applying this plan of Mr. Brandt's to a steel mill I believe is a matter of detail. How it could be applied should be a problem for the controller or accountant. We may not be able to apply it exactly as Mr. Brandt does, but as long as the plan has been worked out successfully, there is no question in my mind but what it can be worked in a steel mill.

One of the most noteworthy results of this scheme is the maintaining of your repair force in times of slack periods of operation. Most of you maintenance men know what you have been through in the past eight years in trying to hang on to a group of skilled workmen. When work slows up in depression times, they leave the vicinity and you are forced to train other men to fill their places.

I believe the Association should be very grateful to Mr. Brandt for the splendid manner in which he has handled this subject, as the results are far-reaching. I had a conversation several weeks ago with Mr. Brandt on this plan and he went into some detail on how it is working in various plants. The results were startling in that in almost every account they set up for these maintenance items there was a generous balance showing they had handled the plan in such a way to result in savings. Those facts alone prove to me that there is no question about the logic of this plan. I hope the rest of you have gotten as much enthusiasm from Mr. Brandt's remarks as I have, and can carry something of this idea with you.



STANDARDIZATION of 440 VOLT A-C POWER and CONTROL Equipment

By D. C. NELSON
Assistant Electrical Engineer

J. RUSSELL POWELL
General Foreman

Jones & Laughlin Steel Corporation
PITTSBURGH, PA.

▲ TO approach standardization of 440 volt equipment it is necessary to view fully what the future holds. The narrowing margin of profit in the steel industry makes it imperative for an economical choice of electrical equipment, yet this equipment must be capable to meet the heavy demands of steel production, and should the need arise, be versatile enough to be salvaged and re-used for another application.

We have found that this point has been almost entirely overlooked in the past by engineers, and with this thought in mind the following items are offered in which 440 volts will play an important role.

In many instances it would be cheaper to break up large concentration of power centers and employ smaller sub-stations, terminating the high voltage transmission lines directly to the transformer primary and using 440 volts for distribution to drive motor generator sets of the smaller capacity. This refers, of course, to shop utility power and not to equipment used to provide power for the large main drives. The savings effected

FIGURE 1—Steel mill sub-station single line diagram of electrical equipment for a by-product plant, showing an undesirable method of using high voltage motors and switchgear.

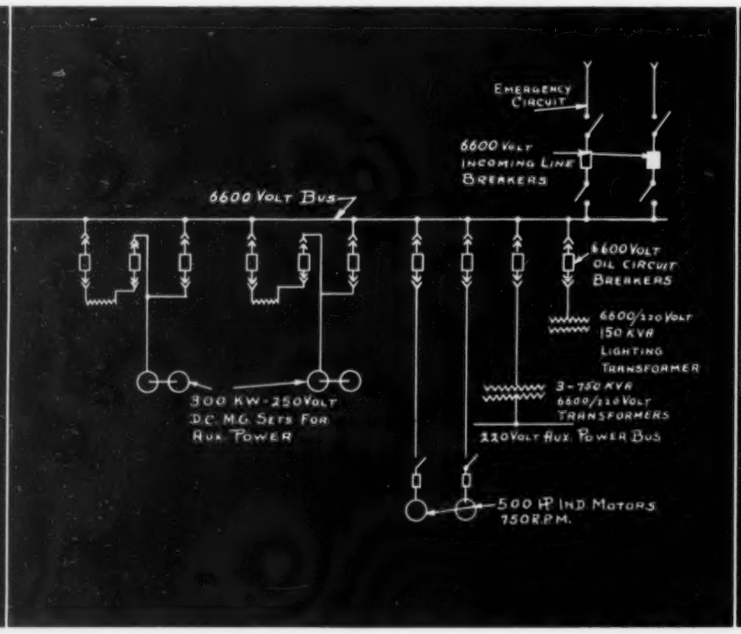
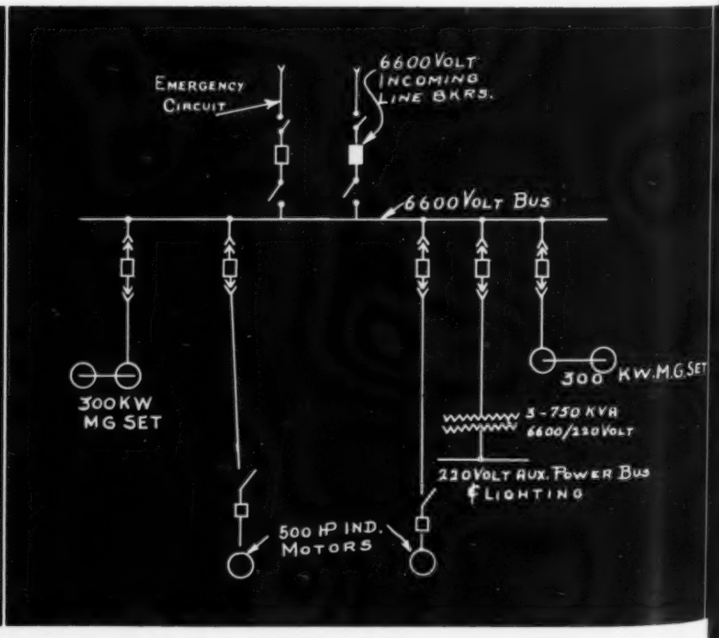

EMERGENCY CIRCUIT
6600 VOLT INCOMING LINE BREAKERS
6600 VOLT BUS
6600 VOLT OIL CIRCUIT BREAKERS
6600/220 VOLT 150 KVA LIGHTING TRANSFORMER
3-750 KVA 6600/220 VOLT TRANSFORMERS
300 KW-250 VOLT D.C. M.G. SETS FOR AUX. POWER
220 VOLT AUX. POWER BUS
500 HP IND. MOTORS 750 R.P.M.

FIGURE 2—Diagram showing the way the same plant would be laid out with the modern methods of today. This particular plant uses 6600 volts.


EMERGENCY CIRCUIT
6600 VOLT INCOMING LINE BKRS.
6600 VOLT BUS
300 KW M.G. SET
300 KW M.G. SET
3-750 KVA 6600/220 VOLT
220 VOLT AUX. POWER BUS & LIGHTING
500 HP IND. MOTORS

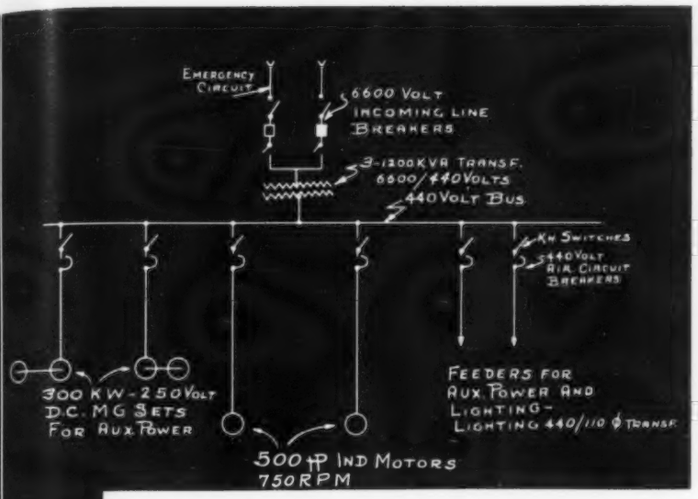

EMERGENCY CIRCUIT
6600 VOLT INCOMING LINE BREAKERS
3-1200 KVA TRANSF. 6600/440 VOLTS
440 VOLT BUS
KN SWITCHES 440 VOLT AIR CIRCUIT BREAKERS
300 KW-250 VOLT D.C. M.G SETS FOR AUX. POWER
FEEDERS FOR AUX. POWER AND LIGHTING - LIGHTING 440/110 ϕ TRANSF.
500 HP IND MOTORS 750 RPM

FIGURE 3—A steel mill sub-station single line diagram of electrical equipment, showing the use of 440 volts. Note the absence of switchgear which in this case proves more economical.

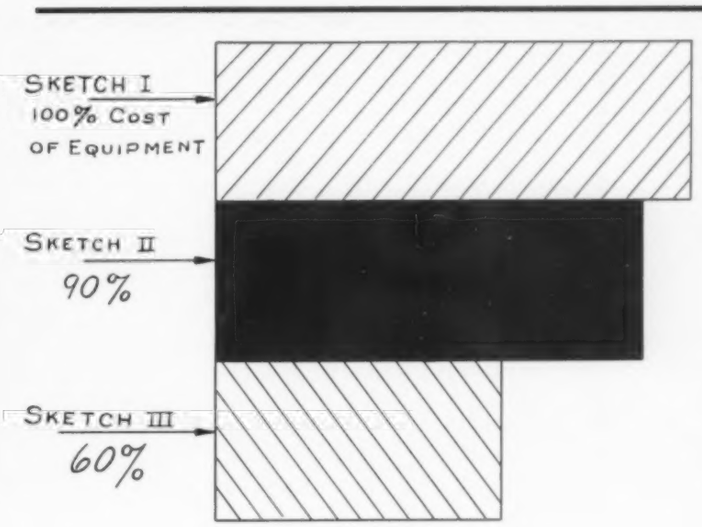


FIGURE 4—Standardization of installation systems, giving good adequate equipment, for use in several capacities resulted in the comparative costs shown above.

by the use of 440 volt drives in the smaller motor generator sets are considerable as the cost of motor switches and motors are much less for 440 volts. Another attractive feature of this system is the removing from the high voltage system possible trouble points which instead of reflecting back become merely a local condition. At what capacity the line of demarcation should be set between the use of high and low voltage motors is difficult to say as it depends upon each engineering problem as it presents itself. However, it appears that it should lie between 400 and 600 kw. capacity. We submit in Figure 1 a typical steel mill sub-station single line diagram of electrical equipment for a by-product plant in which the use of high voltage motors and switchgear was way out of line. Figure 2 shows the way it would be installed today using 6600 volts. Figure 3 shows our recommendations using 440 volts. As you notice the absence of costly switchgear is very noticeable in Figure 3, also the transformer station and high voltage switchgear could be of the unit sub-station type, which of course, can be at any time effectively applied to another location at small cost. There is no reason why for steel mill service this type of sub-station could not be standardized for several capacities, such as being done by the utility companies today. Figure 4 shows comparative costs, the comparison being made by estimating on good adequate equipment in every case.

A check of a typical steel mill area consisting of rod mill, wire and nail mill, tin mill, cold reducing and galvanizing plants shows that it would be possible to concentrate 15,000 kva. of 440 volt power at this point and economically transmit this power to the receiving auxiliary equipment. However, we recommend that this should be broken up into three sub-stations. A few years ago the high costs of attendance would prohibit this but it has been proven that it is possible to use non-automatic sub-stations without attendants if the feeders are provided with reclosing breakers. So it appears that 440 volt transformer banks for ordinary steel mill service will not exceed 4,000 to 6,000 kva. capacity. The question now arises what short circuit current can we expect from this type of system? The answer, of course, can only be approximated. In calculating high voltage short circuit currents, many factors are ignored such as are voltage drop, current transformer reactances,

Co-authors D. C. Nelson (left) and J. R. Powell (right), presenting their paper before members of the Association at the opening technical session of the Annual Convention held in Cleveland, Ohio, September, 1938.

etc., which tend to limit the current. However, when the voltage is lowered to 440 volts we find that these factors are really the limiting factors where the possible short circuit current approaches 40,000 amperes. With this in mind we believe short circuit currents in excess of this magnitude need not be considered on 440 volt systems unless an actual accidental bolted short is made regardless of the capacity of the transformers feeding the fault. Obviously, this figure of 40,000 amperes drops rapidly as we move out in the line away from the power source.

However, there are many points connected close to the main bus which feed power to auxiliary equipment and this condition creates a problem to be solved. What type of equipment can safely rupture these faults? We are not greatly concerned in the larger size installations of auxiliary equipment as the larger contactors and breakers used have demonstrated their ability to withstand this severe service.

The smaller starters and breakers from 100 hp. down have given us trouble. We are acquainted with one particular installation for a 75 hp. motor which twice has blown up its circuit breaker and contactors, making a dangerous center to be around should a short circuit occur.

Investigation showed that short circuit currents in the magnitude of 12,000 to 15,000 amperes was possible. The contactor was protected with a circuit breaker of 10,000 amperes rupturing rating. At the present time this circuit breaker rating is typical of air circuit breakers in the market for this type of service.

In attempting to rectify this condition a study was made as to what type of equipment is best suited for such short circuit protection. To be suitable it must rupture the current in a fraction of a cycle to give protection to the motor starter and yet remain undamaged.

We know from tests and experience that a non-refillable powder packed fuse, whose rating is no greater than four times the motor current rating, will fulfill this condition. However, the trend has been towards the air circuit breaker in order to cut down on the higher maintenance cost and loss of time from the use of fuses. Circuit breakers are preferable to fuses in that they indicate their action, they can be quickly reset, they do not require renewal of parts, and they have less tendency to single phase a motor. They combine the function of fuse and switch. It has been pointed out that with 440 volts and the magnitude of the short circuit currents that exist, the rupturing rating of air circuit breakers as now listed on the market for this application are inadequate. To install a circuit breaker with adequate rupturing rating (20,000 to 30,000 amperes) would be extremely high in first cost. This limits this type of breaker to such service as will justify the higher cost. Some such cases would be a continuous electro-cleaner line, a continuous pickler line, a shearing and classifying train, etc. Another possible solution would be to install a small 440/220 volt transformer bank near these points and use standard 220 volt equipment.

We submit in Table I. a tabulated list of available equipment for various applications. It should be understood that it cannot be rigidly adhered to as each set of conditions calls for a different economical solution and should be used only as a general yard stick. Also, the equipment listed is what we consider available and in many cases we believe that this available equipment does not fill the bill in regards to a good economical installation. Figure 5 is a single line diagram of equipment listed in Table I.

We are familiar with mills which are at present being changed over from 220 to 440 volts. As each problem is different there are no set rules to follow. Different combinations can be worked out employing a 220-440 volt power supply from the same transformer banks to maintain service to the portion of the plant not yet changed over.*

Motors with nine external leads can be used so that they are applicable to either voltage. However, we feel that there should be no compromise once it is decided to go to 440 volts, the ultimate should be 440 volts and not a combination of mixed voltages, unless it is stepped down from the 440 volt supply mains. Should it become necessary to supply a small amount of 220 or 110 volt power it should be done as outlined above.

Other factors influencing the use of 440 volts a-c. are as follows:

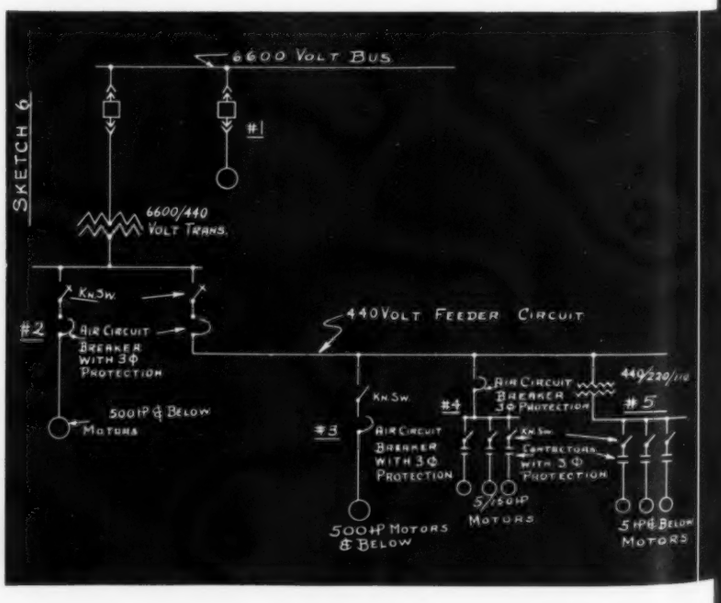
(1) The increase in the steel mills using such devices as electro-cleaners, electro-plating, electro inhibitors, etc., all of which use power from small individual motor generator sets, the motors of course, taking power from low voltage 440 volt circuits.

(2) There are still many direct current constant speed motors that should be changed over to induction motors to take advantage of the lower maintenance costs received from this change.

(3) There are many direct current motors which are applied to equipment such as shearing lines, cleaning lines, wire drawing blocks, roll tables, etc., which obtain their variation of speed by field control. It has proven advantageous in many cases to supply these d-c. motors with power from small Ward-Leonard motor generator sets, the higher first cost being offset with higher yield

* For further information on these combinations consult the A. I. E. E. Journal, September 1935, Vol. 54, No. 9, Page 93. "Leads on Delta Connected Transformers with Mid Taps"—by Noble G. Larson.

FIGURE 5—Below is shown a single line diagram of the available equipment for the various applications listed in Table 1.



and lower operating cost due to the greater ease of manipulation. These motor generator sets are increasing the use of a-c. low voltage and by the same amount decreasing the use of d-c. shop power.

The safe handling of 440 volts should also be discussed. We feel that 440 volts will not cause any more mishaps to the repairmen than 220 volts. Repairmen fear it more and take fewer chances, thus off-setting any additional hazard it may present. We recommend, however, that all 440 volt equipment be generously marked particularly where there is a mixture of voltages, as during a change over. The dead ends on all 440 volt distribution lines should be painted red or some other distinguishing color and the meter leads should be painted likewise. All switches and control boxes should be marked 440 volts so that the repairmen will recognize what voltage he is dealing with.

The use of mazda lamps for testing should be prohibited and instead neon testing lamps capable of withstanding 600 volts should be provided.

Working hot circuits should be discouraged; a plan should be followed whereby responsible parties should provide adequate safety equipment and make the decisions as to whether or not the circuits should be worked hot.

The length of this paper did not permit us to discuss all angles of this problem. In summing up what has been presented we will also add some points not touched on previously that were found while making this study.

The use of 440 volt motors instead of higher voltage motors, where the current does not exceed 1200 to 1500 amperes, should be chosen where ever practical. Current in excess of these values cause magnetic difficulties making it necessary to go to the higher voltages.

Devices with interrupting capacity of less than 20,000 amperes should not be depended upon as fault interrupters on a 440 volt system. Large frame air circuit breakers with an interrupting capacity of 60,000 amperes should be used on main 440 volt busses as feeders. This means from a standpoint of standardization of frame sizes that a 2,000 ampere continuous rating breaker or larger should be used. Feeder circuit breakers should be made automatic reclosing, eliminating sub-station attendants. The dash-pot series overload relays on these breakers should be discarded and induction type three phase inverse time relays should be substituted so that an accurate overload setting can be made to conform with conditions fed, as current transformers are essential for metering and the extra cost would not be so great. High interrupting contactors can be used safely on a feeder circuit where they are connected at any point beyond several hundred feet from the main bus.

For smaller motors the safest installation is either 440/220 volt transformers to step down the voltage, or a group of motors may be placed back of an adequate interrupter, 20,000 amperes or better, with comparative safety; costs, of course, being the determining factor. Considerable work can be done in this field by the manufacturers to make available contactors which have adequate short time ratings and sufficient mechanical strength to hold them together and keep them from welding during the interval required for a back-up breaker to clear. Operations are important in a steel mill and such failures cannot be excused.

For equipment we recommend greater spacings between phases, slate bases instead of compound, changing of present day terminal blocks and the enclosing of bus and main connections. Every motor and feed circuit should have three phase protection. Isolating switches for each main circuit should be provided as well as load break switches on all starters and either an improved

TABLE 1

Motor size hp.	Voltage	Location on system	Interrupting Rating kva.	Continuous rating amps.	Class of service	Diagram No. 5 Item No.
Above 500 hp.	6600	Main system	250,000 and 500,000	1200 and 2000	Main drives, large motor generators, sets, etc.	No. 1
500 hp. and below	440	Close to trans. bank	60,000	2000 and above	Aux. drives, small motor generator sets, etc.	No. 2
500 hp. and below	400	On feeder some dist. from trans.	20,000	150, 300, and 600	Auxiliary drives single	No. 3
150 hp. to 5 hp.	440	On feeder some dist. from trans.	20,000	75, 150, 300, and 600	Auxiliary drives grouped	No. 4
5 hp. and below	220/110	On feeder from 440/220/110 V. trans.	10,000	35, 50 and 75	Auxiliary drives grouped	No. 5

supply method of 220/110 volt for control or adequate push buttons and master switches for 440 volts.

A thermal overload relay for starters using the induction principle and discarding the bimetal strip, which is prone to disintegrate or twist out of calibration at the first fault, is desirable.

With this paper we have been able to offer few solutions as it is beyond our ability to do more than suggest use for the present apparatus. We suggest that some of the major manufacturers give these problems deep consideration and present their recommendations either at a future meeting or to an appointed committee who, in turn, will make proper standardizations as was done with d-c. mill type motors. We hope that this paper will be one of the initiating factors which will help to ultimately find the correct answers to these problems.

DISCUSSION

PRESENTED BY

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G. A. CALDWELL: This excellent paper brings out the present trend toward 440 volt a-c. auxiliary power and the reasons for it. It is the speaker's opinion that the distribution system will usually be most satisfactory and economical when the transformer banks are laid out so that the maximum secondary short-circuit current will not exceed 20,000 amperes, although there are undoubtedly exceptional cases where short-circuits greater than this amount may be obtained. We agree with the authors' statement that short-circuits in excess of 60,000 amperes will rarely be experienced regardless of the size of the transformer bank.

The interrupting capacity of the circuit breakers for 440 volt service requires careful consideration. If, as is sometimes done for higher voltage, the reactance of the source and transformers alone are considered, high values of fault current are obtained. A relatively short run of cable or open bus will decrease the current materially. For a recent test setup, calculations on the basis of source and transformer reactance alone gave a symmetrical rms. value of current of 55,000 amperes. On test only 20,000 amperes actually flowed. When a loop of bus 12 feet long with 10 inches separation between the sides was eliminated, the current as measured was 27,000 amperes; when some 40 feet of open cable was eliminated and the switch under test was directly connected to the transformer terminals, a reading of 33,000 amperes was obtained. In another case the theoretical value of short-circuit current based on transformer reactance alone was 26,000 symmetrical rms. amperes, while the results of the actual tests showed 13,000 amperes. The principal reducing factor was 130 feet of cable in duct. A careful calculation of all the elements of the circuit in both of the above examples gave results that checked within ten per cent of the test value. It is essential therefore to consider all elements of the circuit when determining the short-circuit current.

From these results it is evident that the only possibility of obtaining short-circuit currents in the neighborhood of 60,000 amperes is when the motor and control equipment is connected almost directly across the transformer secondary terminals.

On the basis of this information it appears that for some of the main feeder breakers it may be desirable to have a breaker with a rating of 60,000 amperes interrupting capacity. However on the feeder circuits at some distance from the transformer, it is evident that a breaker with a short-circuit rating of 40,000 amperes is ample and in many cases even a 20,000 ampere short-circuit breaker is sufficient.

With the recent development in air circuit breakers they will repeatedly interrupt the rated short-circuit currents and still be in good operating condition. They are also suitable for frequent operations so that the breaker itself can be used for starting motors and thus avoid the magnetic contactor. This arrangement is particularly adaptable for motors of 100 hp. and above that run continuously or have infrequent starting and stopping.

Our company is completing the development of a new breaker of this type and a 3000 ampere, 3 pole breaker is on display at our exhibit. It is equipped with the de-ion grids which have been applied to high voltage air and oil circuit breakers with such satisfactory results. Tests show that this breaker has a remarkable interrupting capacity and is ample to take care of anything that may be expected on 440 volt secondary circuits.

In addition to this high interrupting capacity breaker there are also breakers available rated at 20,000 amperes short-circuit capacity.

We know that motors from 500 to 5 hp. and even smaller must be fed from this 440 volt system and that many of the smaller motors may be operated

several times per minute. Such service demands a heavy duty magnetic contactor similar to the d-c. steel mill type and such contactors are available. These contactors are designed with the wide pole spacings as suggested by the authors and have many other features making them suitable for steel mill service. However, these contactors cannot be expected to interrupt the short-circuit current should it occur between the controller and the motor as the rated short-circuit capacity of the contactors as standardized by N. E. M. A. is 10 times the contactor rating.

Therefore it is desirable to protect these contactors with a suitable breaker which may be a feeder breaker or it may be a branch feeder breaker protecting a small group of motors driving some particular machine. We have built several controllers where the circuit breaker and the magnetic contactors are all built into one control panel, the controller being of the deadfront type. The breakers and control switches are operated from the front of the panel and all magnetic contactors are mounted in the rear of the panel.

When applying magnetic contactors to a system of this type the minimum size of contactor in ampere rating must be given considerable attention. It is our feeling that if the short-circuit currents are to exceed 10,000 amperes the minimum current rating should not be less than 100 amperes if the contactor is expected to withstand the short-circuit. If the magnetic contactor is properly backed up with an instantaneous trip breaker, the contactor should carry the short-circuit currents without material damage. The contactor tips will undoubtedly tend to separate and in all probability will weld before the breaker clears the short. There will be sufficient thermal capacity in the shunts and other current carrying parts to prevent them acting as a fuse before the breaker opened.

The writer sees no particular difficulty in short circuits on 440 volt systems if the points mentioned above are given the proper consideration.

G. E. WHITTAKER:. When the author got the chart with the comparative cost base, did he take into consideration the copper necessary to feed the large motors, such as 500 horsepower, 440 volts?

Have they noticed whether or not there is any greater serviceability for a motor of that size in 440 volts than any other voltage, such as 2300 or 2400? Do they have less breakdowns and less trouble?

D. C. NELSON: Answering the first question, the comparative cost base of the chart took into consideration the cost of equipment installed. Regarding the second question, no records are available.

E. C. MARSHALL: In the charts giving the relative cost I understood it was 60 per cent or 90 per cent or 100 per cent. I assume that was the relative cost of equipment used. I would like to ask whether that value is based upon the purchasing price of the equipment or whether it was the price of the equipment plus the probable maintenance.

I am thinking now of the maintenance of an oil circuit breaker as compared to the maintenance of a contactor around 1000 or 1500 amperes on a system where the feeders are under ground in the form of cables. Is there any comparison on that basis, and furthermore, has there been any experience with these large contactors and is the maintenance high?

D. C. NELSON: Charts giving relative cost were based on price of equipment plus installation costs. No comparison was made on probable maintenance cost. From our experience we would say that the maintenance costs on high-voltage circuit breakers are higher due to periodical inspections required.

F. O. SCHNURE: The authors have shown the trend away from large transformer banks distributing low voltage power over a large area toward smaller units located near each load concentration. However, they mention 4000 to 6000 kva. as the maximum capacity which seems rather large unless serving heavy auxiliaries. In most cases 1500 to 2000 kva. should be sufficient. Recently a study of a 4000 kva. load, so distributed that it could adequately be served from one bank, disclosed the fact that instead of one large bank, two 2000 kva. banks could be installed at a saving of over $10,000, because the larger installation would have required the more expensive high interrupting capacity circuit breakers on the low voltage side.

Separating a mill low voltage system according to load concentrations should add but little to the primary switching equipment as two or more circuits can be placed on an oil circuit breaker, separating them with an air break disconnecting device if thought necessary. Trouble on these systems rarely reach the primary breaker and even so, the outage on two or three transformer banks so connected is no worse than if served by one large bank.

The 25 cycle, 440 and 550 volt distribution systems prevalent in the older steel mill installations do not present the problems due to voltage drop caused by the impedance of the circuit as do the now more frequently used 60 cycle frequency. This is another strong argument in favor of smaller diversified systems.

Three conductor armored cable from the primary switch to the load concentrations can be safely run overhead in conduit or on messenger, or underground either with lead covering or in a non-hygroscopic compound buried in the ground. Attention should be given to the spacing of low voltage feeders if of open construction.

The authors have indicated a preference for 440 over 220 volt distribution. With advances being made in motor insulation and protected control apparatus, 440 should be much preferred to the lower voltage because of the greater economy in cost and routing of distribution circuits with the sacrificing of but little in safety considerations.

In general the recommendations in the paper have been for protective equipment that will be more reliable. It remains for the manufacturer to provide same without raising the cost to an obstructive point.

I. N. TULL: I believe the authors of this paper have given their subject plenty of consideration, and that's just what it takes to arrive at the proper voltage to use for any given plant. I think we all agree there

can be no set rule establishing a proper voltage to use indiscriminately.

For a good many years, particularly in 25 cycle plants, 220 volts was considered to be the only proper voltage to use for motors of small rating. There were many reasons, some very good ones in fact, for this belief. Among them were safety, reliability, the use of a few circuits of large cross-sectional copper runs of short distances, lack of satisfactory protective control equipment on the market for the higher voltages, and the economics involved.

As regards safety, we learn from the public utilities that more fatal injuries are suffered from contact by persons with 115 volt lighting circuits than by contact with 440 volts. I think this shows that more care is being given to the installation of the higher voltages than is in the lower ones, and that this accounts for the increasing interest of municipal authorities in code revisions and inspections.

The 440 volt motors and control on the market today offer a variety of choices to meet special atmospheric conditions, so that reliability can be attained, if pains are taken in making proper applications.

Proper circuit design of low tension circuits has to be carefully worked out in order that high reactive drops are not encountered. As the reactive drop due to a 60 cycle current is nearly two and one-half times that of a 25 cycle current, the skin effect is more pronounced and it is necessary to use multiple circuits of small cross section rather than single ones of large. Therefore, the 440 volt system, using half the current that a similar 220 volt system would have and consequently half the cross-sectional copper, inherently is the least expensive.

As to the maximum size of transformer bank for supplying the 440 volt circuits, at present I don't incline towards exceeding 1000 kva. A transformer of this rating will ordinarily have a reactance of about five per cent, which means its current output will amount to 20 times normal at times of terminal short circuit, if on a system of large enough capacity to sustain voltage under such a circumstance. At any rate, I think we can expect at least fifty per cent of this current to show up in a failure on an average mill feeder, line and arc drop accounting for the balance.

Normal full load current being about 1300 amperes, fifty per cent of short circuit current would be 13,000 amperes, and at present, small motor breakers are not economically available to handle this requirement satisfactorily. We don't want our main feeder breakers kicking out on motor lead faults, and if we exceed around these capacities, our individual motor breakers will be subjected to more grief than they were intended to be.

Another point concerning safety. Where plug-in points are made on high capacity, 440 volt circuits, suitable disconnecting means should be available, so that the plugs cannot be put in or pulled out when alive. This requires interlocking of some sort, and there are on the market some safety switches interlocked with the plugs. For small capacities these are still economically not popular, and we are in hopes of the development before long of satisfactory, popular priced equipment of this nature that will protect against the hazard at present existing in a number of plants to my knowledge.

After all, the selection of proper voltages is one means to the end of over all economy, and profit in industry. There is a good deal of money involved in a large plant layout, and the decision on voltages to be used is one of the earliest to be made in a new mill program. We must move carefully in establishing the proper voltages, for once set up, a change later on will be costly. Such a paper as Messrs. Nelson and Powell have given us here is food for much thought.

F. MOHLER: From the discussion we have had, we certainly can see that this is a live issue, and I think everyone is interested in it. There has already been some activity among the manufacturers, and I can assure you that the manufacturers are awake to the necessity for adequate 440 volt control.

I believe there is very little discussion required in regard to the air circuit breakers for feeding large motors off the 440 volt bank (or for feeding blocks of power for supplying groups of smaller motors), because we have 60,000 ampere air circuit breakers which are adequate for these purposes. I think our biggest difficulty lies in this last classification, that is, the blocks of power that are consumed by small motors and are backed by an adequate interrupting capacity breaker.

These smaller motors require individual control, but there is a definite demarcation between two general classes of control. So far we have only talked control of the so-called general purpose type. Now, general purpose control has no acknowledged interrupting rating. It is not equipped with instantaneous overloads. It is merely equipped with thermal overload relays, and to protect it, it is necessary to use fuses, or small circuit breakers.

However, there have been developed contactors with interrupting ratings, and that class of control is something that is fairly new. There have been some installations of it, and we have recently run tests on a so-called 150, 300 and 600 ampere contactor.

Just to see the limitations of safety, we have tried several combinations. We have tried a 150 ampere contactor with barriers and extra pole spacing. We have tried a 150 ampere contactor with barriers and extra pole spacing. We have tried the 300 ampere contactor without barriers, fully enclosed, and also with the doors open. We have tried 300 and 600 ampere contactors with barriers and without barriers.

Interrupting ratings of 10,000 amperes have been established for the 150 ampere contactors; for 300 ampere contactors, an interrupting rating of 20,000 amperes; and for 600 ampere contactors, an interrupting rating of 30,000 amperes; all of which we feel are perfectly safe.

These are the results of actual tests, and even without barriers we have interrupted these ratings, although from the standpoint of additional safety factor, we recommend that barriers be used with equipment of this type.

If you are going to use the control as an interrupting device, you should, of course, have instantaneous overload protection, as well as thermal overload protection. Instantaneous overload protection should clear that particular contactor at a point which is not

FIGURE 1

covered by the breaker which backs it up. In other words, the general breaker used today for distribution is in the neighborhood of 2000 amperes with 60,000 ampere interrupting capacity. If you use a 150 ampere starter, there is naturally a gap between the interrupting capacity of that contactor and the circuit breaker, thus, to adequately protect the contactor, that contactor should have its own instantaneous trip clear at a value depending upon the size of the motor with which it is being used.

There are certain cases where these contactors will come close to the bus, and it is possible to get a short circuit at currents beyond their rating. In other words, although the continuous current capacity might call for a 150 ampere contactor, you might have to use a 300 or 600 ampere contactor for interrupting protection.

Mr. Nelson mentioned the use of thermal overloads. There have been developed the so-called thermal inductive overload relay, which is not only an excellent thermal overload relay, but it is also an excellent reactor. In other words, it will limit the current of that particular starter and to a great measure protect that starter.

We have built some control of the dead front construction, as has been mentioned here today.

In Figure 1 we have the so-called high interrupting capacity contactor, with the switches in front, and with the contactors on the back. All the wiring and relaying is enclosed, so the man can work on the relays or on the control wiring without coming into contact with 440 volts. There is an overhead bus that directly connects with the line switch, and there is very little danger of coming in contact with 440 volts.

Along with that there are certain small motors that can be operated as a unit, and if one has a short circuit you can afford to trip out the whole group in that particular case. Here, somewhat smaller contactors, but certainly not less than 75 amperes, can be used in a group and protected by small circuit breakers having the necessary interrupting rating.

In Figure 2 are the high interrupting capacity contactors, one above the other, so as to get two units in one enclosure. Here is an air circuit breaker protecting five smaller starters.

I believe you can see what is being done along the lines that you desire. It is always a pleasure to hear you gentlemen talk and not have to guess what you want. Almost anything can be built, but it sometimes costs money.

I heard a little remark up here about cost, but I believe if we can get together on a particular problem, adequate equipment for that installation can be put in at a reasonable cost. I don't believe we have to talk about a lot of money to give adequate protection on our 440 volt control. I hope to see in the near future some cooperation between the manufacturers and the steel mill associations to set up some kind of standards. I know the manufacturers are working on it, and I am sure they would be glad to have the Association of Iron and Steel Engineers work with them.

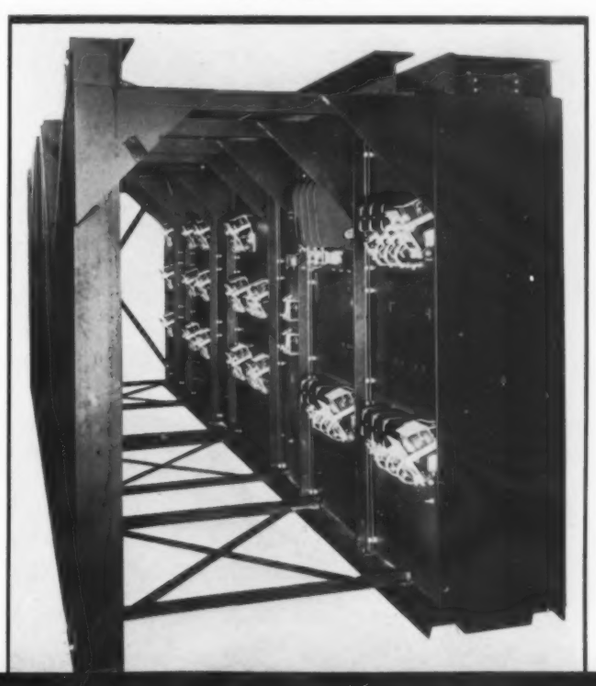
WRAY DUDLEY: I should like to ask what has been the reaction of the men operating machines where the 440 volt motors have been applied, whether or not opposition has developed from them due to the use of the 440 volt motors.

E. C. MARSHALL: I would like to comment on that. Since 1918 we have used 440 volts at our Indiana Harbor plant and during the past ten years there have been no objections from the operator's point of view, and there certainly have been decided advantages in the use of the small conduits and smaller cables.

H. L. WILCOX: There would seem to be little objection to 440 volt control from the operator's view point if the masters are substantial and of such a nature that he is not brought near to the actual control circuits.

Occasionally in machine tool work, where the push buttons and the platforms may be saturated with moisture or what we call solvent oil or cutting oil, it is necessary to keep the control voltage down to a lower value in order to prevent leakage currents and the occasional shocks to the operator but in these cases it is an easy matter to provide either 110 or 220 volt control through a small transformer from the 440 volt main circuit. In this way one may enjoy all the advantages of 440 volts in the motor and feeder circuit without any disadvantages from the standpoint of the operator.

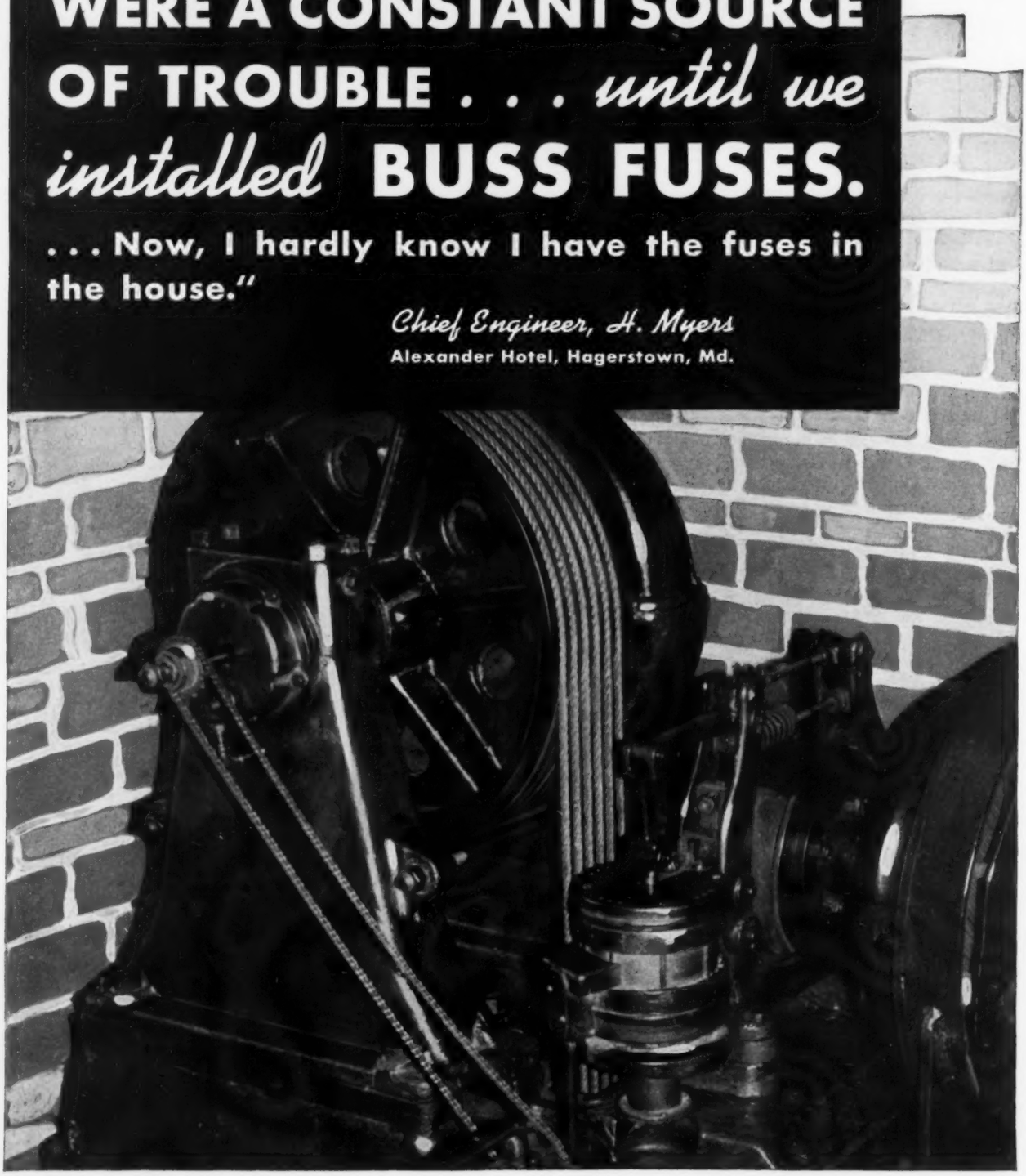
FIGURE 2



"OUR ELEVATOR CIRCUITS WERE A CONSTANT SOURCE OF TROUBLE . . . *until we installed* BUSS FUSES.

. . . Now, I hardly know I have the fuses in the house."

Chief Engineer, H. Myers
Alexander Hotel, Hagerstown, Md.



BUSS

HERE'S THE STORY,

as related by Mr. Myers

"THE 200 ampere fuses protecting our elevator circuits were a constant source of trouble blowing on an average of 10 times a month.

"About 5 years ago I installed BUSS SUPER-LAG Fuses of the same amperage. Since then I don't recall having as many as one blow per year —in fact I hardly know I have fuses in the house."

Why Should Any Plant Suffer Needless Blows **that can be prevented?**

Like all good fuses BUSS Super-Lag fuses protect plant and equipment against electrical hazards—and they DO MORE—as stated by Chief Engineer Myers, they protect against unnecessary and senseless shutdowns.

Naturally there are sound reasons for this kind of performance.

The design of the BUSS FUSE-CASE is such that it reduces to a minimum any chance for poor contact to develop in the fuse itself.

Hence heating from poor contact —that so often causes needless blows — is practically wiped out.

The Super-Lag development in the FUSE-LINK gives BUSS FUSES a retarded blowing point—or long time-lag that permits them to hold on without blowing when harmless overloads are piled on circuits already loaded.

Thus when motors start under load—or machines jam momentarily—or any of the hundreds of things occur that cause temporary, harmless over-currents, BUSS Super-Lag Fuses keep right on holding and the plant keeps right on running and nobody even thinks about the BUSS fuses that are holding down the job of protecting against electrical hazards.

The book "How to Select Renewable Fuses" tells the story. A free copy is yours for the asking.

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BUSSMANN MFG. CO.
University at Jefferson
ST. LOUIS
Division McGraw Electric Company

WHY BUSS FUSES
DON'T BLOW NEEDLESSLY
10 FEATURES in the design of the FUSE-CASE help make it possible..
The SUPER-LAG development in the FUSE-LINK completes the job.

Super-Lag FUSES

BUSS 1914 Silver Anniversary 1939 25 years progress in fuses

Pictorial

BIRMINGHAM C

Over 450 attended the 1939 Spring Conference

Sou

The 1939 Spring Conference marked the first national meeting to be held in the Birmingham area, and was held on the twentieth anniversary of the founding of the Birmingham Section of the Association. The success of this meeting was particularly gratifying to one who was instrumental in forming the Birmingham Section, A. H. "Pop" Swartz, shown (upper left) with President C. C. Wales and T. B. McElray.

The technical session held Monday morning was presided over by R. R. Thomas and C. C. Pecu (left). Authors of papers presented at this session included H. A. Travers (lower left), J. J. Phifer (below), and W. A. Mandy (lower left, opposite page).

Review of CONFERENCE

Southern operations of much interest to Conference participants

Significant of the interest taken by steel men in this district so singularly fortunate in its tremendous wealth of all the raw materials for the production of iron and steel is the fact that the registration at the Conference totaled over 450 prominent steel operators and engineers, who all expressed a keen interest in the Southern operations.

At upper right are shown Thomas Chalmers, Brent Wiley and A. B. Haswell at the Monday noon luncheon.

Among the more than two hundred Northern visitors attending the Conference were L. A. Umansky, James Farrington, J. D. Wright, and F. O. Schnure (right) and J. S. Murray and F. E. Flynn (lower right).

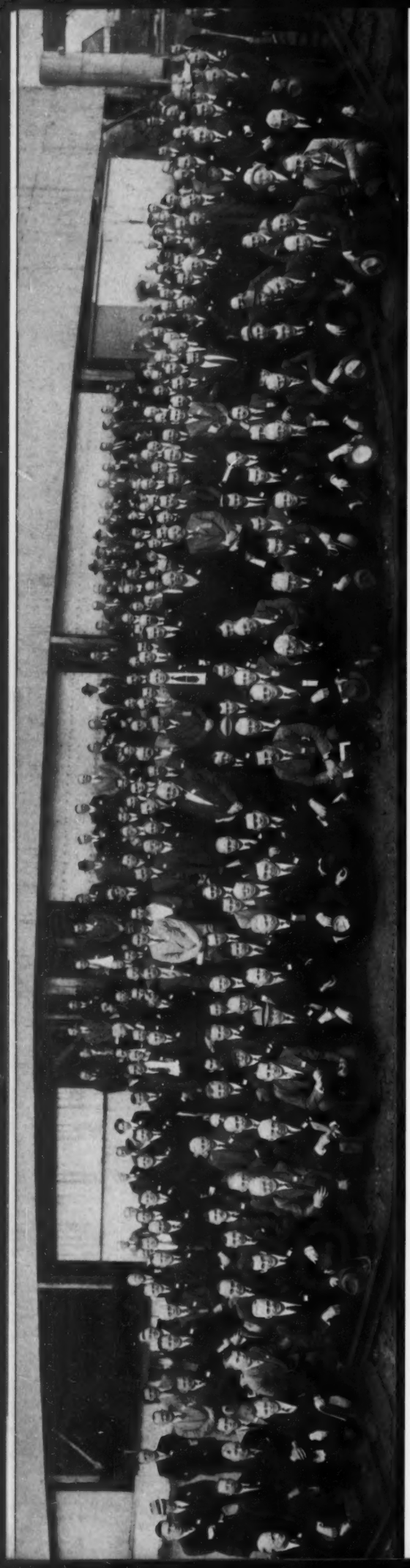
Also among the visitors were J. J. Huether, L. V. Black and K. H. Runkle (upper left), and L. A. Wynd, J. D. Donovan, J. H. Graft, and H. E. Davis (left).

On Monday afternoon the first inspection trip was held, visiting the plant of the American Cast Iron Pipe Company. Against a background of operations in this plant are shown F. P. May, John Moxley, and T. R. Moxley (lower left).

At the dinner held Monday evening, a welcoming address was delivered by Robert Gregg, shown upper right with President C. C. Wales. Following dinner, a technical session was held, consisting of papers by E. A. Hawk (lower right), M. P. Burns (opposite page, lower left) and J. E. Urquhart (opposite page, upper left). This session was presided over by H. T. Watts (opposite page, upper right).

The entire day Tuesday was devoted to an inspection trip of the vast properties of Tennessee Coal, Iron and Railroad Company. Approximately 400 members and guests attended this trip, which was made on a special train supplied by the company. Stops were made at Ishkooda ore mine, at the rail mill, the cotton tie mill, the new blooming mill and hot strip mill, and the new tin mill. To the right is T. E. Hughes discussing plant operation with R. L. Bowron and James Arthur Smith.

At lower right are A. J. Boynton, Karl Landgrebe, and R. R. Thomas partaking of the luncheon served by the Tennessee Company in the annealing department of the new tin mill.



Above is a view of part of the group on the inspection trip of Tennessee Coal, Iron and Railroad Company plants.

Karl Landgrebe (above) ably served as narrator, using the public address system installed on the train.

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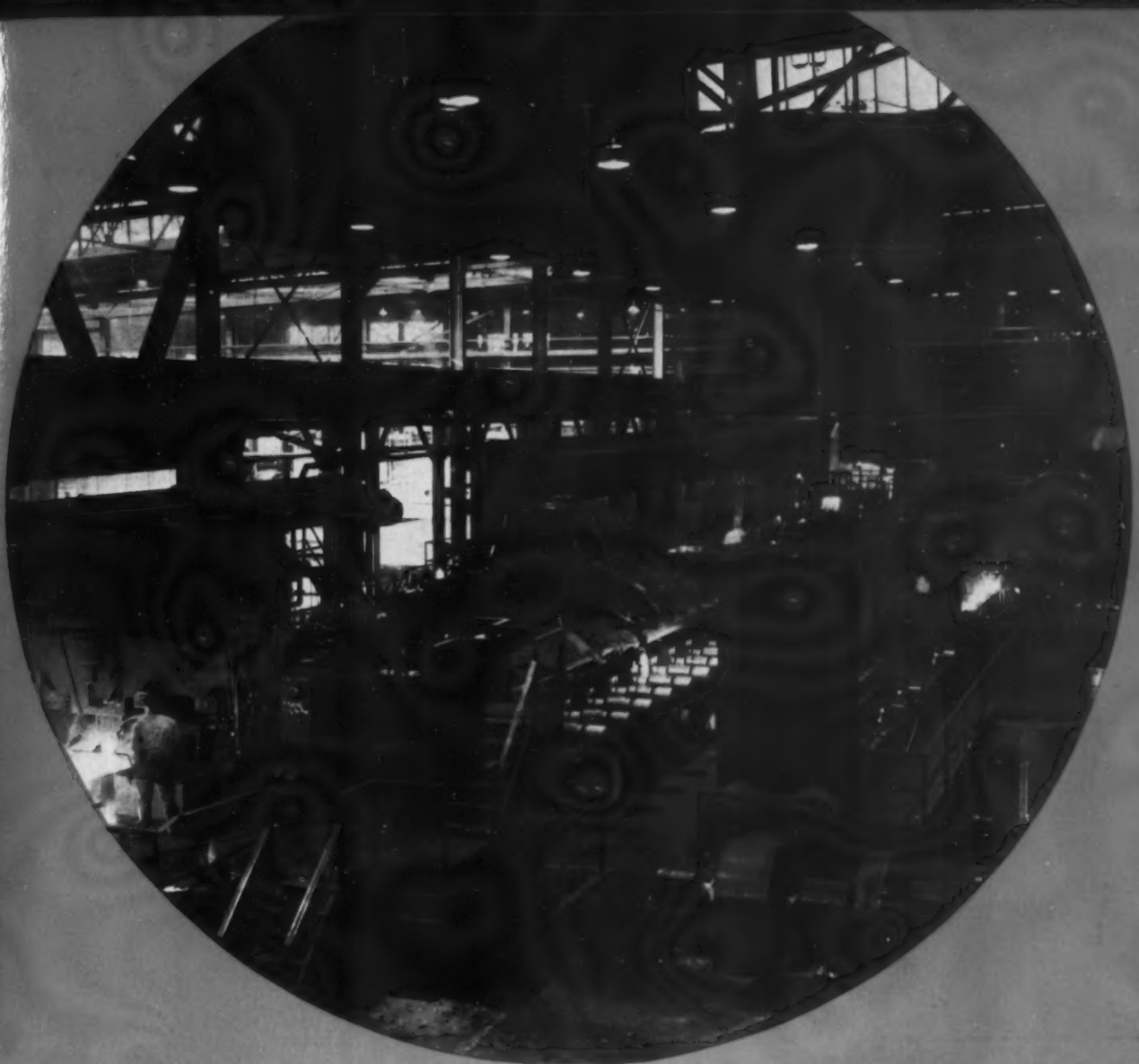
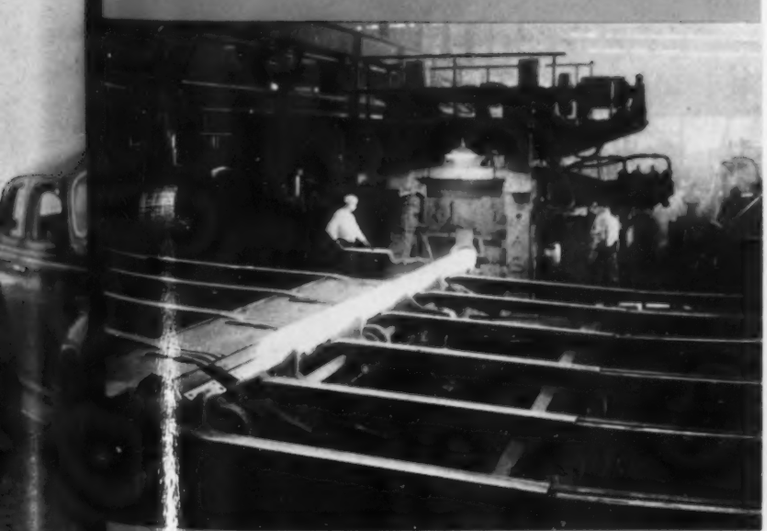
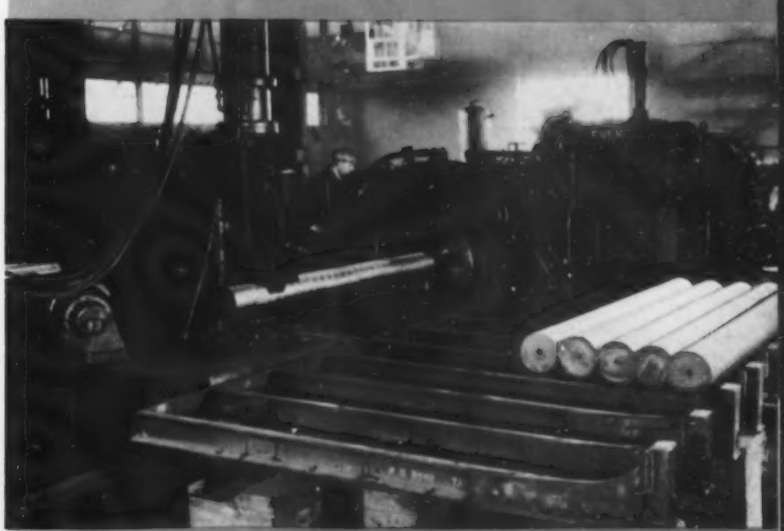
Much of the success of the conference may be attributed to the excellent cooperation of the committees from the Birmingham membership, headed by Birger Thele and F. M. Sturgess (below).



YOUNGSTOWN SHEET AND TUBE COMPANY

Expands Seamless Facilities





YOUNGSTOWN SHEET *and* TUBE COMPANY EXPANDS *Seamless* FACILITIES

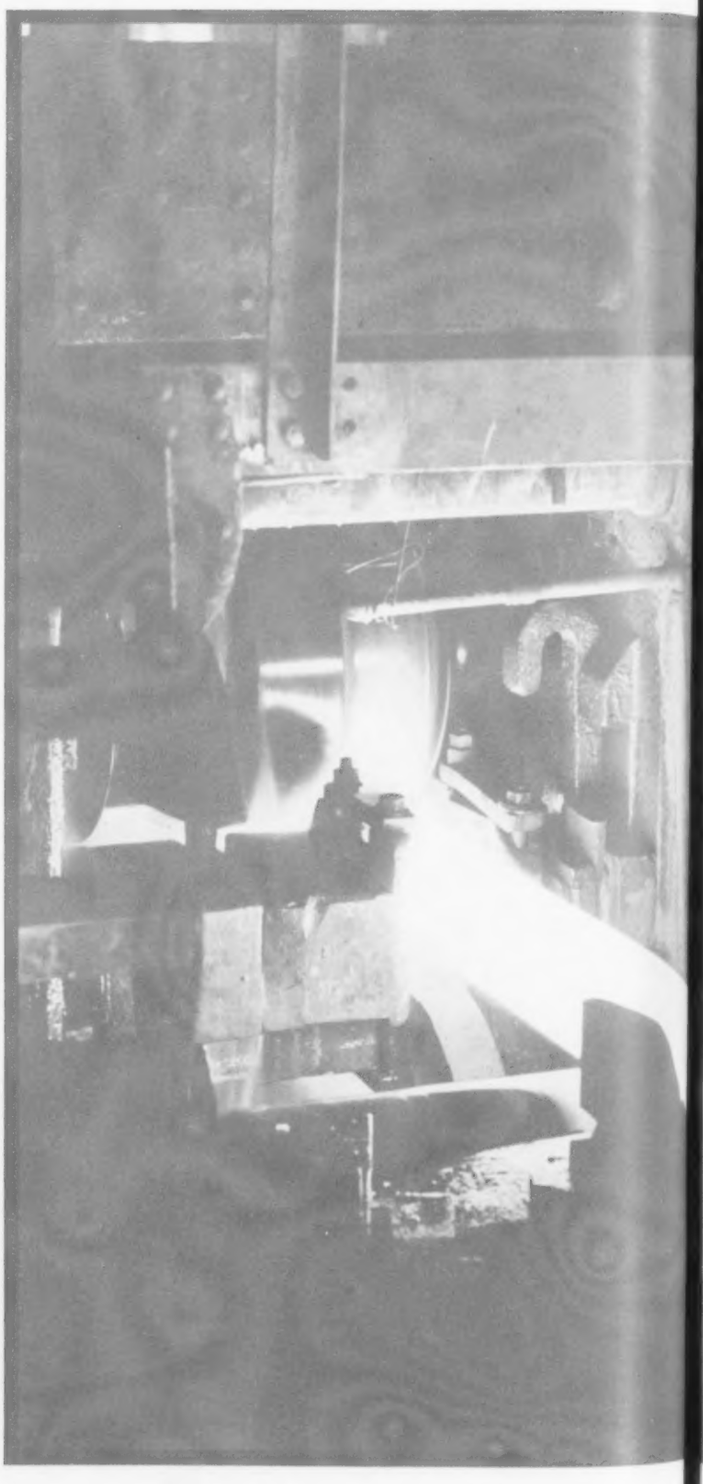
By T. J. ESS

Personnel photographs by

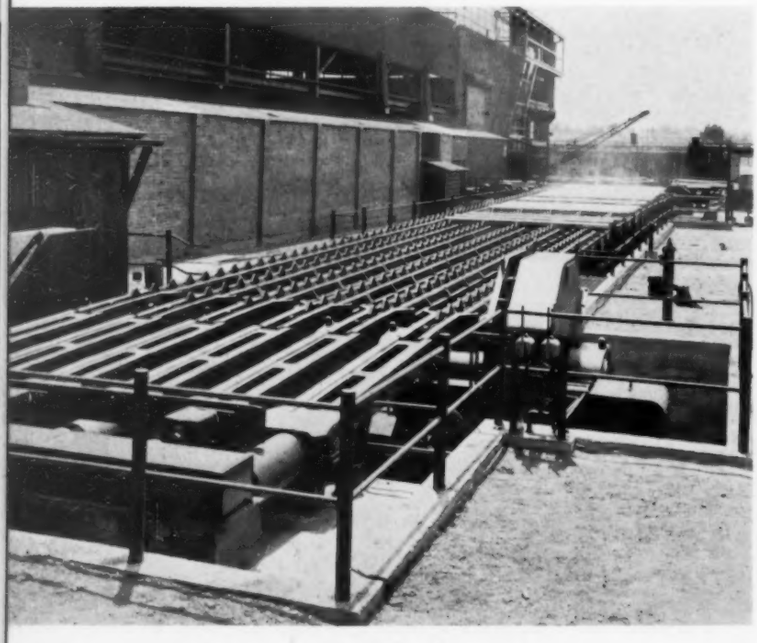
WALTER A. BARTZ

▲ THE general development and improvement of the seamless pipe division of the Youngstown Sheet and Tube Company in their Youngstown properties include several new units which materially increase facilities for making this product. The expansion is the result of the increased demand for seamless pipe and tubing due to its gradually widening field of application in industry. It includes the first large seamless tube mill built in this country in eight years.

Although the process of piercing using the principle of diagonal rolling is essentially the same as when originated about fifty years ago, improvements incorporated in the design and layout of the new mill are so extensive



View of cooling bed which handles rounds 4½–14½ inches in diameter at speeds of 6–48 inches per minute, and is powered by a variable voltage drive.

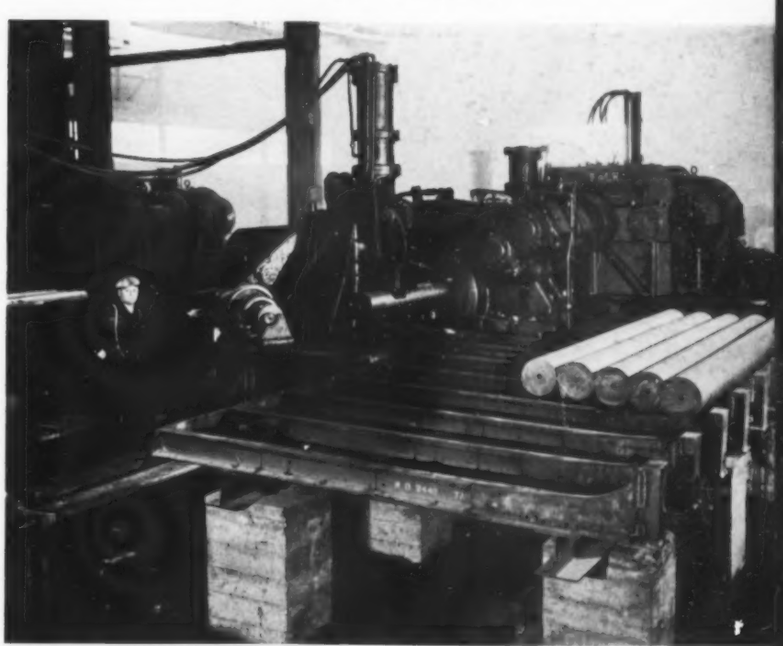


W. B. GILLIES,
Vice-President

as to render comparatively new mills rather obsolete.

The piercing process places rather severe requirements on the steel used in seamless tube production and renders soundness of the original billet of great importance. As a result, the steel used is specially selected,

Round billets for seamless production are peeled to assure freedom from surface defects. Two billet peelers are installed, each of 1000 tons per day capacity.

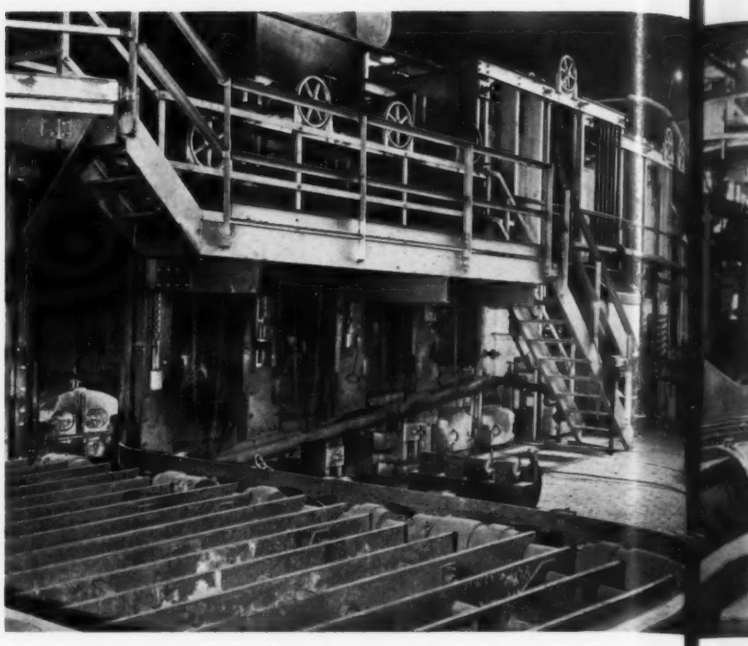


and must meet exacting tests. Normally, all seamless steel is produced in the well-planned open hearth of the Brier Hill works, and is poured in hot-topped big-end-up molds, with ingot weights ranging from 8600 lb. to 14510 lb. Ingots are stripped and then heated for rolling in six blocks of regenerative soaking pits of four holes each, and two blocks of two holes each, all fired with producer gas.

BLOOMING MILL

When ready for rolling, ingots are drawn and placed on an electrically operated ingot buggy, which conveys them to the blooming mill approach table. The blooming mill is a 40 inch mill, driven by a 44 inch x 76 inch x 60 inch twin tandem compound reversing engine, with a maximum speed of 140 rpm. Screwdowns are driven by two 100 hp. d-c. motors, as are the front and rear mill tables. The manipulators are of the hydraulic type.

Blooms to be used for seamless production are subsequently rolled in the intermediate mill, either with or without a reheating operation. Bloom sizes for direct rolling vary from 12 in. x 13 in. to 15½ in. square, while sizes for reheating may range from 8 in. x 8 in. to 12 in. x 15 in. These sizes are dependent upon the size of round to be finished. In general, finished sizes above 4¾ in. diameter are rolled direct, with the smaller sizes passing through a reheating operation.



Rounds are re-heated in two new furnaces of walking beam type, each with a capacity of 50 tons per hour.

J. L. MAUTHE,

General Superintendent,

Youngstown District

REHEATING FURNACES

Reheating facilities consist of a triple-fired continuous furnace with a hearth 19 ft. 6 in. wide x 69 ft. 9 in. long. The main heating zone is 52 ft. long, and is fired top and bottom, through burners spaced across the width of the furnace. In addition, two auxiliary burners have been installed firing through each side wall about mid-way in the main heating zone. These burners have boosted furnace capacity with no noticeable effect on its economy. The balance of the furnace length is devoted to a solid-hearth soaking zone, which is overfired through six burners spaced across the end wall of the furnace. Each firing zone is equipped with automatic combustion control. Air for combustion is pre-heated to temperatures of 650-800 degrees F. in a refractory tile recuperator. The furnace is fired with natural gas, using up to 90,000 cu. ft. per hour, and is capable of heating up to 60 gross tons per hour.

A twin pusher of special design moves the blooms through the furnace in either one or two rows. Blooms are pushed out of the furnace by a solid ram, with rack and pinion drive.

The intermediate mill is a new two-high reversing 35 in. unit, with rolls 38 3/16 in. in diameter x 84 in. body length running in composition bearings. It is driven by a 4000 hp., 600 volt, d-c. motor. Mill screws, of 1¾ in. pitch, provide a top roll lift of 27 in. and are driven by a 100 hp. compound motor. Manipulator and side guards are electrically driven. The mill is designed for rapid roll changes with universal couplings that can be quickly retracted and pulled away from the

Close-up of the first piercing mill, a heavily designed unit in which the billet is rough pierced for subsequent rolling.

rolls, and with wide windows in the housings that allow rolls to be easily removed.

Rounds from 5⅞ in. to 13½ in. in diameter are rolled on the intermediate mill direct from the 40 in. blooming mill, at rates of 75-140 tons per hour. Blooms for subsequent rolling on the 24 in. mill, ranging from 5 in. x 5 in. to 8 in. x 8 in., are also produced on this mill.

Product leaving the intermediate mill is cropped and cut to length on a 72 in. hot saw driven at a peripheral speed of 20,000 ft. per min. by a 750 hp., 2300 volt, 560 rpm. motor through 44 V-type belts. A variable speed motor gives a feed regulation of 9—54 ft. per minute. Sizes up to 14 in. x 16 in. may be cut on this saw. After being cut to length, rounds are transferred to a centering machine, then stamped and conveyed out through the end of the building to a chain-type cooling bed 120 ft. long x 15 ft. wide with an adjustable speed of 6—48 in. per minute, dependent upon the rate of production of the intermediate mill. The centering operation is required in order to provide a definite center point for the piercing mandrel to start its penetration.

Smaller sizes, ranging 3—6¼ in. in diameter, may be finished on the 24 in. mill. Billets from the intermediate mill, after cropping on the hot saw, are then transferred to the 24 in. merchant mill tables. This mill consists of six two-high stands, in a cross-country layout, and is driven by a 34 in. x 68 in. x 60 in. cross-compound twin tandem horizontal condensing engine running at 80 rpm. The stands are driven through individual bevel gears from a line shaft paralleling the mill and directly connected to the engine. The first four stands of the 24 in. mill roll in a direction opposite to the flow of material through the bloomer and intermediate mills. After the fourth stand, the steel is again transferred to another mill line, where the last two stands again reverse the direction of flow.

The 24 in. mill has a final delivery speed of about 600 ft. per min., and produces at a rate ranging from 50 tons per hour for the smaller sizes up to 100 tons per hour for the larger sizes.

Located 131 ft. beyond the last stand of the 24 in. mill is a 66 in. hot saw, driven by a 200 hp., 2300 volt induction motor, at a peripheral speed of about 18,000 ft. per min. Lengths of 15-32 ft. are cut on this saw, and handled over two hot beds 32 ft. wide x 92 ft. long, from where they are handled by overhead crane. When cuts smaller than 15 ft. are required, a multiple cut is made on the 66 in. saw and the product moves on to a 48 in. hot saw, driven by a 150 hp., 220 volt a-c. motor. Product from this saw is handled by overhead crane.

BILLET PEELERS

In order to insure a product free from imperfections which might subsequently produce a faulty or inferior product, two round billet peelers are installed, in which a cut is taken on the rounds sufficient to eliminate surface defects and expose any deeper defects which may then be removed by chipping or scarfing. In this manner, the pickling operation is eliminated. The two peelers are duplicate units, each with a capacity of

J. D. JONES,

Chief Engineer

about 1000 tons per day. Rounds are brought to the machines by electrically driven conveyors, and are kicked off and fed into the machine by an entry carriage which pneumatically grips the back end of the round. An electrical drive in the carriage moves the billet forward into the cutting head, consisting of six hard alloy steel cutters in a revolving head. The head is driven by a 250 hp. motor at speeds of 4—40 rpm. After the round has proceeded through the cutting head to about half its length, it is pneumatically clamped by the traveling discharge carriage, which pulls it through the rest of the way. The round is then discharged on to a conveyor which carries it to the inspection and conditioning beds.

The speed of peeling depends on the size and grade of steel. The traveling carriages have a speed regulation of 37—230 in. per min. The machines are manually operated. Rounds which are cambered to such an extent as to prevent peeling are first straightened on a 1000-ton horizontal hydraulic press.

C. W. EDWARDS,

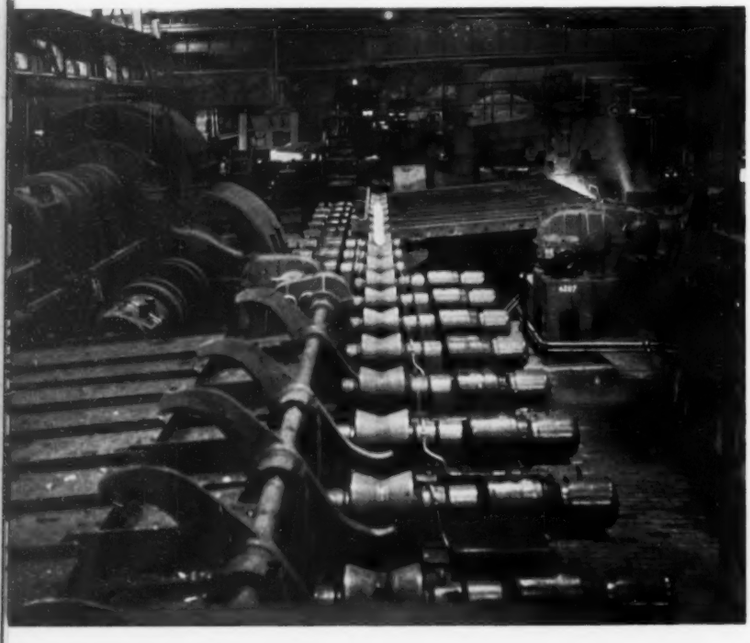
Superintendent,

Brier Hill Works

SEAMLESS MILL

The new seamless mill, with a rated annual capacity of 300,000 tons, is installed at the Campbell works of the company, and is a modern semi-automatic unit, using the plug or high mill. Rounds are brought to the mill in railroad cars from the previously described round mill at the Brier Hill works. The billet yard, 288 ft. long x 96 ft. wide, is served by two 10-ton overhead cranes, and contains two 22 x 36 ft. loading docks. From these docks a conveyor, 323 ft. 6 in. long, composed of grooved 12 in. diameter rollers on 4 ft. 6 in. centers individually driven by 2 hp., 820 rpm. motors at a conveyor speed of 219 ft. per min., runs to the heating furnaces. Two motor-driven pushers on each furnace move the rounds from the conveyor into the furnace, and permit charging in one or two rows as desired. The greater part of the steel lengths fall between 7½ and 11 ft., and are therefore charged in a double row. The small portion of the billets shorter than 7½ ft. may be charged in multiple lengths and subsequently cut before piercing.

View of conveyor table between the first and second piercing units. Rollers are equipped with anti-friction bearings and driven by individual motors.



HEATING FURNACES

There are two continuous triple-zoned walking beam heating furnaces, spaced on 52 ft. centers, with hearth dimensions of 83 ft. x 25 ft. The main heating zone is about 60 ft. long, and is fired top and bottom by six burners in each location. The steel is carried through this zone by a unique design of a walking beam mechanism, constructed of water-cooled tubular members within the furnace. The water-cooled members are insulated with a refractory material to reduce heat loss and to reduce the effect of the cooled surface on the steel being heated. The tubular members pass down through slots in the furnace hearth, which are provided with movable sealing covers.

Beneath the hearth are located two complete and distinct walking beam mechanisms, of heavy construc-

J. K. SUTHERLAND,

Assistant General Superintendent

tion, which may be operated separately or in unison, depending on whether the furnace is heating a single or double row of billets. The mechanism is operated by oil-hydraulic pressure of 750—1000 lb. per sq. in., with valves automatically operated to give the desired walking beam cycle.

The soaking zone is about 20 ft. long, and has a slightly inclined solid hearth, down which the billets roll by gravity. This zone is overfired through six burners.

A 13½ in. flat suspended arch forms the furnace roof, while the sidewalls are composed of 13½ in. of firebrick plus 4½ in. of insulation.

Each furnace has a rated capacity of 50 gross tons per hour. Fuel used consists of producer gas in the two top zones, and natural gas in the bottom zone. Automatic combustion control is applied to each firing zone, with temperature control in the soaking zone. Furnace pressure is also automatically controlled. Air for combustion is preheated in a refractory tile recuperator located in the rear of each furnace.

Billets are thoroughly and uniformly heated to temperatures of 2100-2300 degrees F., and are pushed from the side of the furnace by a motor-driven water-cooled pusher bar on to the idler rolls of the furnace discharge tables, from where a kick-out moves them to the furnace delivery table 13 ft. distant. This table is 196 ft. long, and consists of 12 in. diameter grooved rollers, 15 in. long, individually driven by 2 hp. motors, giving a conveyor speed of 467 ft. per min. Located in this table is an automatic oxyacetylene cut-off machine, which cuts lengths ranging 4 ft. 6 in. to 11 ft. This table also extends back to the billet yard to assist in emptying the furnace in cases of emergency.

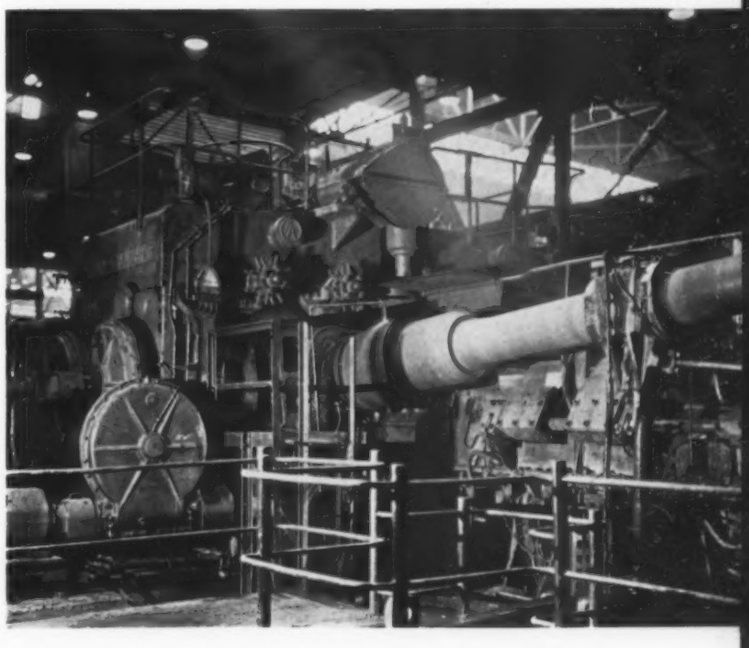
PIERCING MILL

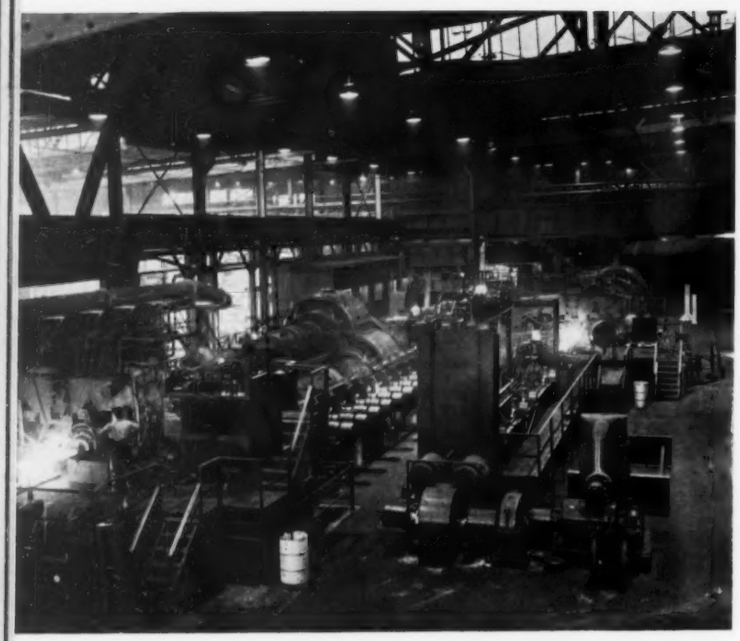
From the furnace delivery table, billets are moved on skids to the No. 1 piercer line about 30 ft. distant. In this skid table is placed an oxyacetylene gas burner device, mounted on an adjustable carriage, for centering billets not already centered.

No 1 piercing mill is a heavily designed unit driven by a 5000 hp., 6600 volt, 360 rpm. synchronous motor through a double reduction gear unit having a ratio of 5.05:1, located about 65 ft. in back of the mill. Between the gear drive and the main drive spindles, which are 16 in. in diameter, breaking spindles and universal joints are placed, supported by a dummy stand for each unit. The main mill housing, which weighs 119 tons, is the heaviest ever built for a seamless tube mill. Heavy design and the extensive use of anti-friction bearings combine to give these units stability and rigidity. Piercer rolls are 42-46 in. in diameter, with 19-24 in. roll necks running at a speed of about 71 rpm. in roller bearings. The roll cradles are adjustable for angles from 5 degrees minimum to 12 degrees maximum. A normal angular setting on this mill is about 10 degrees.

Inlet troughs to the piercer are adjustable in height in order to accommodate billets of varying size. The

Rear view of one of the piercing units, showing drive spindle. Each piercer is driven by a 5000 hp., 6600 volt, 360 rpm. synchronous motor.





General view showing No. 2 piercer in left foreground, with No. 1 piercer in the right background. The second piercer expands and elongates the rough pierced blank.

adjustment is effected by means of manually operated jacks.

The steel is pushed, centered end first, into the rolls of the piercing mill by a pneumatic pusher operated from a cylinder of 7½ in. diameter with a stroke of 17 ft. The billet is grasped at diametrically opposite points by the inclined rolls, and is drawn forward and compressed at these points. The revolution of the rolls causes these points to continually change, which, coupled with the tapered design and consequent greater peripheral speed of the rolls, sets up a twisting action on the billet surface, while simultaneously pulling the billet forward. Thus, a small hole is formed and enlarged at the center of the billet as it moves forward.

The small opening so formed is enlarged by the action of the piercing mandrel, the point of which is placed a little in front of the roll centers, so that the billet is forced entirely over the mandrel before leaving the rolls. When piercing is completed, the mandrel bar is backed out of the tube which encircles it, a cool mandrel placed on the bar, and the process repeated on the next billet. If billet heating is uneven, the mandrel tends to move toward the hot side, making an eccentric tube blank.

Billet sizes may range from 4½ in. to 13 in. in diameter, with lengths running up to 18 ft. 6 in. The maximum length of the pierced billet from the first piercer is 26 ft. 6 in. The water-cooled alloy piercing bar, which, with the mandrel, revolves at the same rate as the billet, is carried on a motor-driven traveling carriage with a 32 ft. 10 in. travel, equipped with adjustable slowdowns and stops in both forward and reverse directions. Thrust of the bar is carried by a thrust block of the marine or anti-friction type incorporated in the traveling carriage. The rear end of the bar is provided with a spherical type thrust head of special design,

C. J. SIEGLE,
General Superintendent,
Tube Division

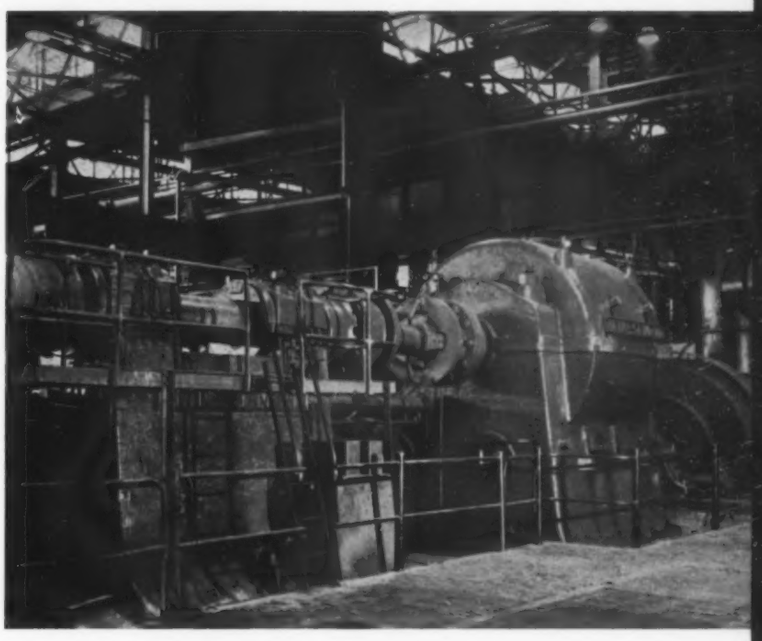
H. E. ENGLEBAUGH,
Superintendent,
Seamless Tube Mills

which reduces whip on the bar and wear on the thrust block. In making small sizes, the tendency of the bar to sag is eliminated by special carriers provided to support the bar. The carriers are synchronized with the bar drive, and work automatically.

From the outlet table, which is equipped with screw-operated adjustable guides, a kick-out places the rough pierced tube on a skid transfer leading to the approach table to No. 2 piercer. This table is about 135 ft. long and is located about half way between No. 1 and No. 2 piercing lines. It also runs back to the No. 1 inlet skids, so that billets may be brought from the furnace directly to No. 2 piercer if desired. The kick-out mechanisms which lift the billets and tubes out of the various runner troughs on to the conveyor skids are double-throw, with two arms, making a half revolution with each operation, always in the same direction. This speeds up operations, as no delay is encountered in waiting for a return stroke of the kick-out arms.

Another kick-out and skid table brings the tube to No. 2 piercing mill, which is a duplicate of the first mill, except that the rolls are 46-50 in. diameter, and will accommodate a rough pierced tube up to 17 in. diameter x 26 ft. 6 in. long, and permit a delivery length up to 39 ft. This mill is placed 86 ft. 3 in. longitudinally from No. 1 unit, and is staggered about 31 ft. laterally. It is also driven by a 5000 hp., 6600 volt, 360 rpm. synchronous motor, through a gear ratio of 4.67:1, giving a roll speed of about 77 rpm. The thrust block on No. 2 mill has a maximum travel of 45 ft. 2 in. A normal angular roll setting of about 9 degrees is used on this mill.

The second piercer operates in the same manner as the first unit, except that its function is to expand and

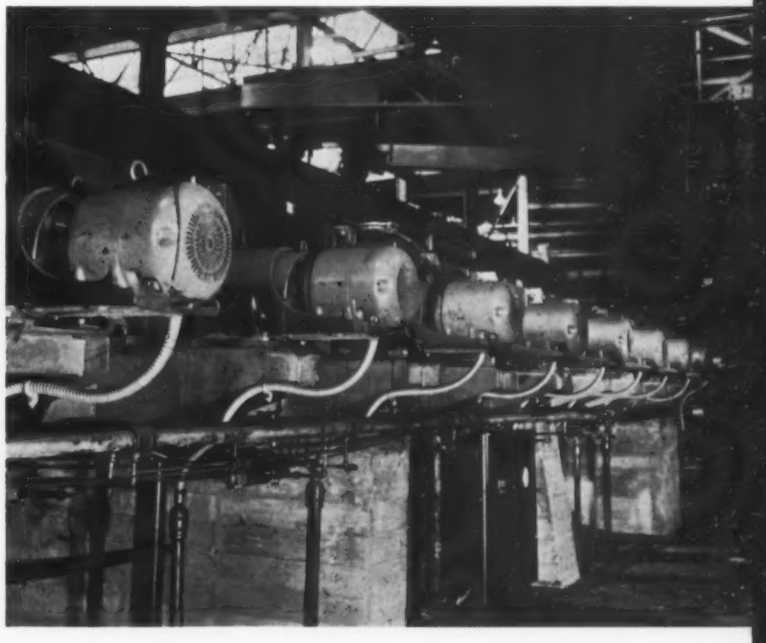


View of one of the double reduction gear units through which the piercing units are driven. The breaking spindle is shown next to the gear unit.

HERBERT DAVIS,

Assistant Superintendent,

Seamless Tube Mills



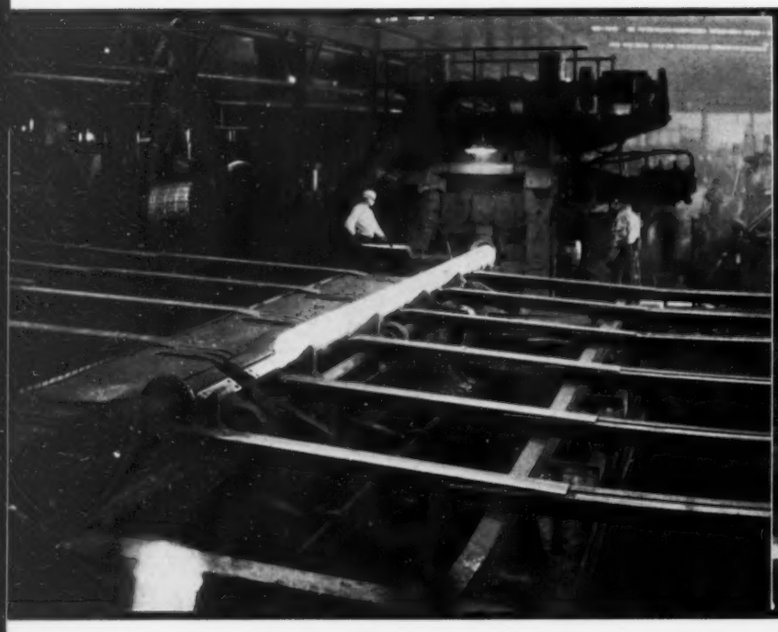
Individual motor drives are installed on the grooved rollers used in the furnace charging conveyor and in the conveyor table between the two piercing units.

elongate the previously pierced billet. The walls are further reduced in thickness, the tube is elongated, and the diameter increased.

After No. 2 piercing mill, the next rolling operation is performed in the high mill, or plug mill, located about 80 ft. beyond and 55 ft. to the side of No. 2 piercer. Skids bring the tube to the mill, where a pusher ram operated by a 8 1/64 in. diameter pneumatic cylinder, and capable of a total travel of 39 ft. 6 in. pushes it into the mill.

The grooved rolls in the plug mill are 28-38 in. diameter x 56 in. long, and are directly connected to the 2000 hp., 6600 volt, 69.2 rpm. synchronous motor. The bottom roll is counter-balanced and operated by means of a pneumatic cylinder. The mill table is laterally adjustable to permit the use of different roll passes.

speed of about 185 rpm. through a 2.1:1 gear reduction by a 700 hp., 2300 volt, 393 rpm. slip ring induction motor. Rolls 29-38¼ in. in diameter are set at a 6 degree inclination, and are separated by a space but slightly less than the diameter of the tube to be reeled. Roll surface is so curved as to contact the tube for several inches of its length. The tube is pushed into the mill by the action of the table rollers and jack rolls, and is rolled over a mandrel. As the rolls revolve in the same direction, the tube and mandrel also revolve as the tube is drawn between the rolls. Double bell guides on the entry side of the reelers restrict the whip of the rear end of the tube as it passes through the rolls. The tube emerges from the reeling operation perfectly round, practically straight, with a good surface. After the mandrel bar is withdrawn by traveling electric carriage,



The pierced and expanded tube blank passes to the high or plug mill, where it is rolled over a mandrel between grooved rolls.

Following the reelers is a five stand sizing mill, the stands of which are inclined 45 degrees from the vertical in alternately opposite directions.

The tube is rolled over an alloy mandrel supported on a rod in a similar manner as in the piercing mills. As more than one pass is made through this mill, it is necessary to remove the tube from the mandrel rod rapidly. When the tube has passed through the rolls the top roll is raised by a counterweight, and stripper rolls, 4 ft. 6 in. long x 2 ft. 4 in. diameter, located 5 ft. 6 in. from the mill center line, are brought to act on the tube, returning it rapidly to the entry side of the mill, ready for the next pass over a larger mandrel. In this way the tube is reduced to the size and gauge desired.

After two passes on the plug mill, the tube is moved over skids to the reelers, of which there are two set side by side in parallel lines. Each reeler is driven at a roll

the tube passes to a sizing mill about 150 ft. distant, consisting of five stands grouped in a space of 23 ft. 4 in.

The sizing mill stands do not stand vertically, but the housings are inclined at 45 degrees, successively in the opposite direction, so that adjacent stands are at right angles to each other. The 32 in. diameter rolls are so designed that the pass grooves in all rolls are in a straight line. This mill is driven by a 700 hp., 2300 volt, 393 rpm. slip ring induction motor, through 4.97:1 gearing, producing a roll speed of 79 rpm.

The finished tube then passes over a chain-type conveyor cooling bed 42 ft. wide x 53 ft. long at a speed which may be varied from 3 to 12 ft. per min., and on to a conveyor extending back to the normalizing fur-

nace. This is a furnace with an effective hearth 51 ft. wide x 42 ft. 6 in. long, of continuous walking beam type. It has a capacity of 204,000 lb. per hour when heating large tubes from an average temperature of 800 degrees F. to 1550 degrees F. soaking temperature. Each furnace has a preheating zone, a heating zone and a soaking zone, with automatic combustion and temperature controls on each zone. The fuel is coke oven gas, over-fired into the furnace through a total of 76 burners. Sidewalls are 9 in. of fire-brick with 3 in. of insulation, while the suspended roof is 9 in. of brick with 4½ in. of insulation.

As the tube leaves the normalizing furnace a conveyor some 240 ft. long carries it back to the cooling beds, of which there are three, totaling a length of about 170 ft. These beds may also be used in connection with the first bed, mentioned above, to convey tubes directly from the mill without progressing through the normalizer.

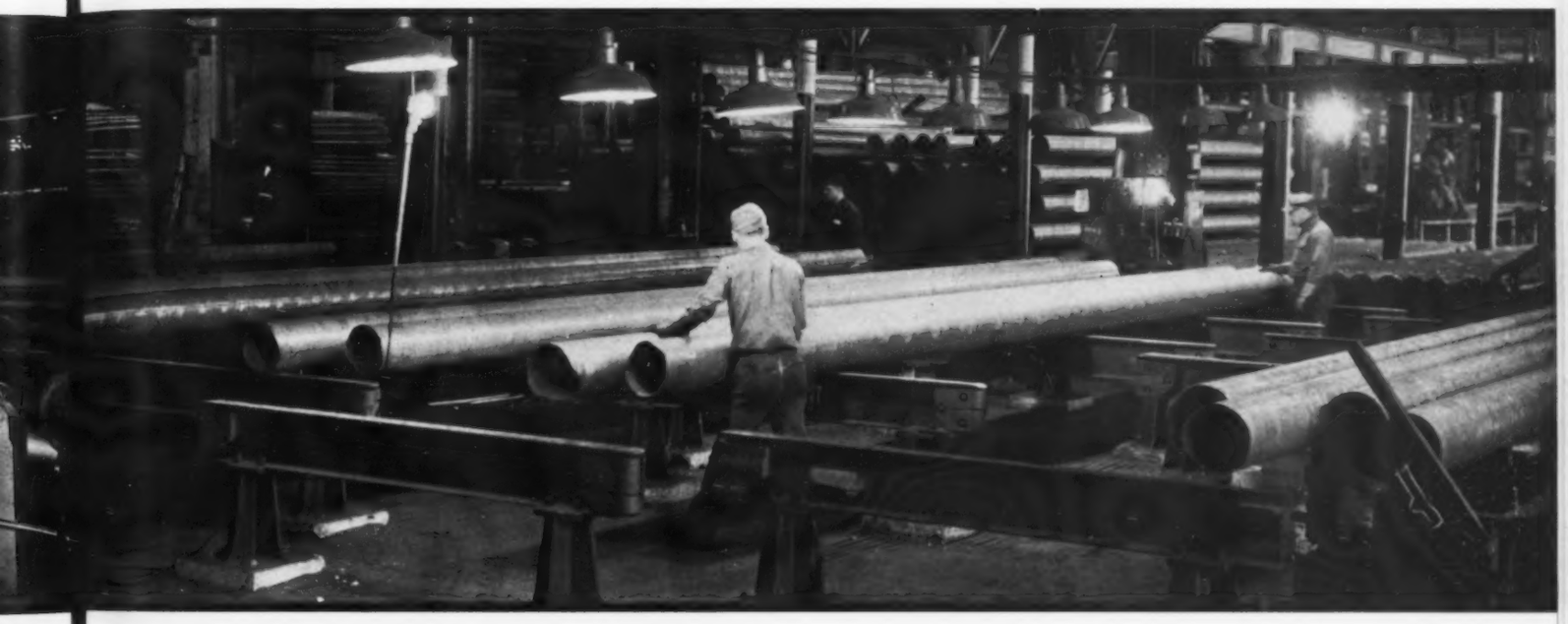
The length of every section of pipe is automatically recorded at the cooling beds. This length is also transmitted back to an indicator at the high mill, giving the roller an accurate check on his product.

Throughout the mill, all main bearings and moving parts are automatically lubricated by central grease and oil systems. Siren signals serve notice of any failure in lubrication systems, as well as in the water supply system.

A pipe straightening machine of the cross-roll type, with three idler rolls 18 in. long x 22 in. diameter and two 3 ft. 5 in. long driven rolls fixed at a 20 degree angle, is located after the cooling beds. Tubes pass through this machine and on to the finishing operations.

The seamless mill is located in a double-bay building 620 ft. long and totaling 200 ft. wide. Mill layout is such as to promote production and efficiency. From the first piercer on, the material flow is progressively forward and laterally to the right, with each successive lateral movement being to a slightly lower elevation, so that the material rolls across the skid tables from the action of gravity.

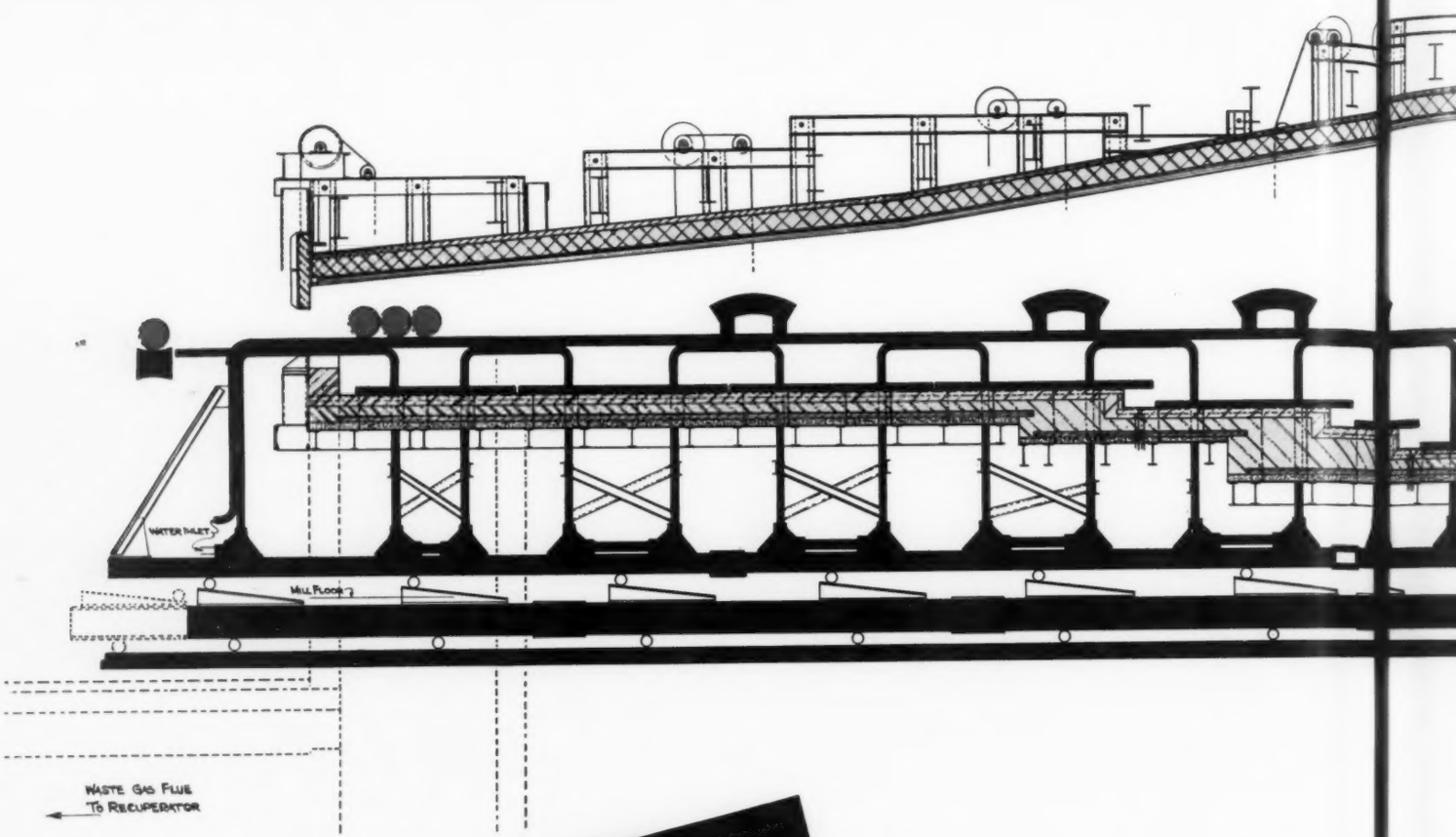
Finishing equipment is located in four parallel bays which form a continuation of the main mill building, giving a total width of about 325 ft. and a total area of about 270,000 sq. ft. Here is located all the necessary equipment for finishing and testing pipe from the new mill as well as the original mill installed sbout twelve years ago. Pipe is finished plain end, upset, beveled for welding, or threaded. The equipment for both mills includes six pairs of cut-off machines, fifteen pairs of threading machines, four coupling screwing machines, four hydrostatic testing machines, two straighteners, two lathes, a bucking machine, a drifting machine and three upset machines.

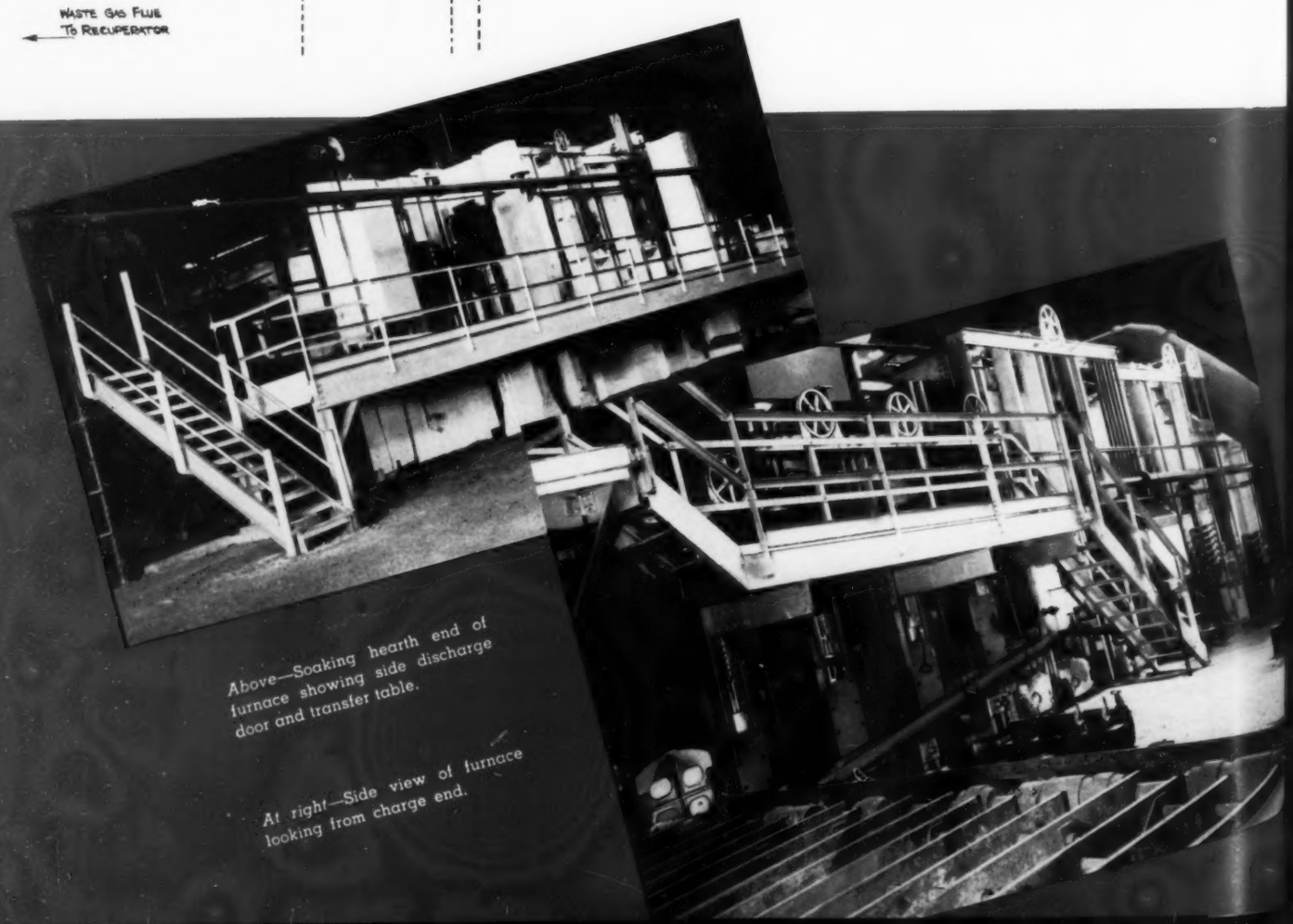


The finished tube is carefully inspected, tested, and the ends finished off in plain end, upset, beveled for welding or threaded.

Located in an adjacent building paralleling the new mill is the No. 1 tube mill, a smaller unit producing tubes ranging 1½—7 in. diameter, with an annual capacity of 125,000 tons. This mill consists of a single piercer driven by a 2000 hp. motor, followed by a plug mill, two reelers, a five-stand sizing mill, and a twenty-stand reducing mill. The mill is fed by two 16 ft. x 67 ft. continuous furnaces, and can take billets up to 12 ft. long x 6¾ in. diameter, and produces pierced lengths up to 25 ft. long.

SC FURNACES WITH WALKING BEAM

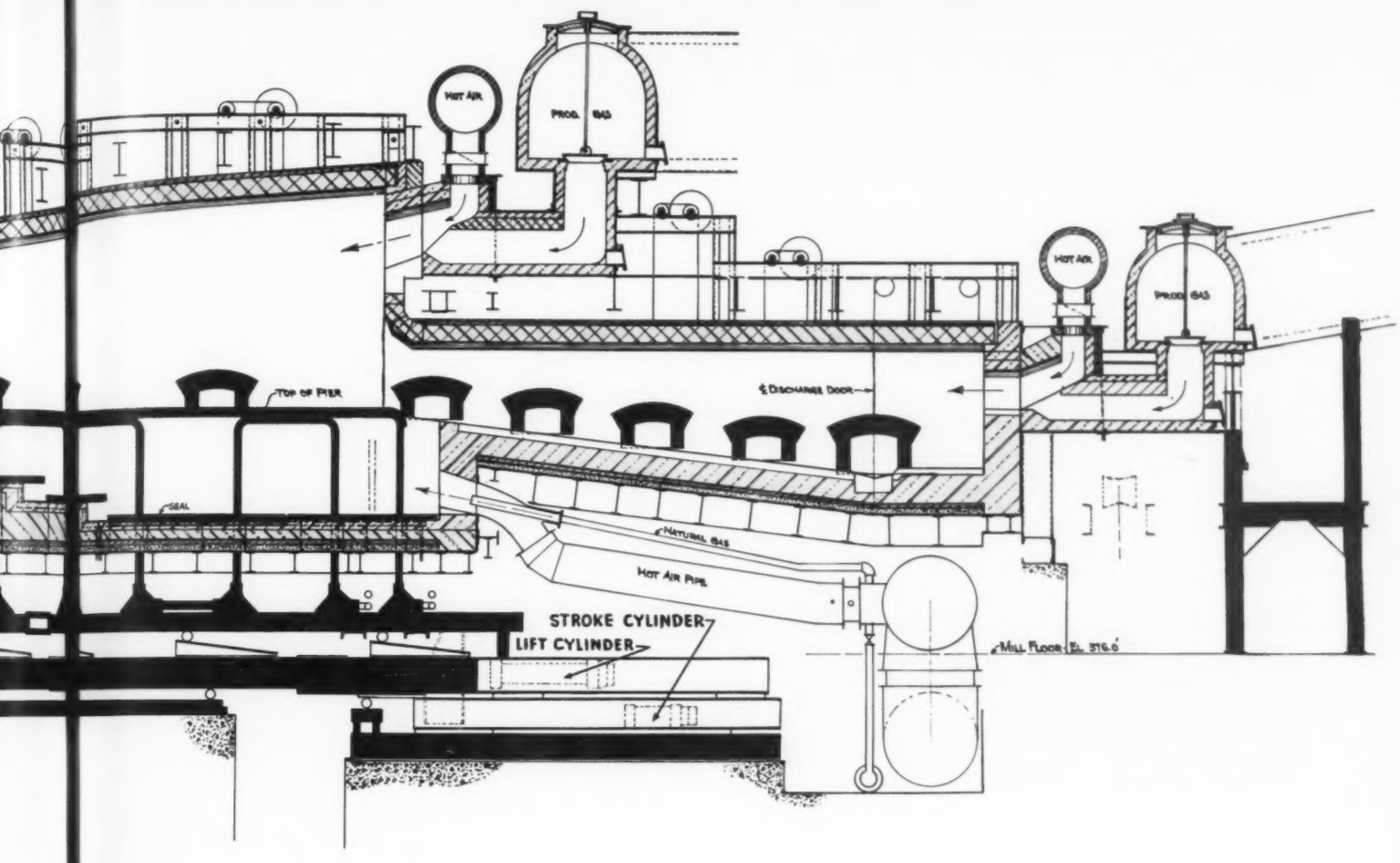




Above—Soaking hearth end of furnace showing side discharge door and transfer table.

At right—Side view of furnace looking from charge end.

CONVEYORS FOR HEATING ROUNDS



Marking a radical departure from conventional practice, the two Round Heating Furnaces each with a rated capacity of 50 tons per hour, at the new Youngstown Sheet and Tube Piercing Mill are equipped with Walking Beam Conveyors. It is believed that this is the first application of a walking beam conveyor at such a high temperature and on such a large scale . . . By means of the walking beam conveyor, the rounds are conveyed from the charge end to the inclined soaking hearth. From here the billets roll down the inclined soaking hearth to the discharge doors where they are pushed out the side of the furnace by means of a water-cooled peel to a common discharge table located between the two furnaces . . . There are two complete and distinct hydraulically operated walking beam conveyors in each furnace. These may be operated together or separately depending on whether the furnace is heating a single or double row of billets. The walking beam mechanism is constructed of water-cooled tubular members within the furnace. The water-cooled members are insulated with a refractory material to reduce the heat losses to a minimum and at the same time provide a radiant surface to the steel being heated thereby reducing the shadow on the steel . . . The use of walking beam conveyors in these furnaces has resulted in very marked, substantial savings in operating labor and fuel. Only six operators per turn are required for both furnaces. The fuel consumption is 150 to 200 pounds of coal (or equivalent) per ton heated, depending on tonnage and size of billet. The use of walking beam conveyors has also made possible more uniformly heated billets. The combination of these factors has materially reduced production costs . . . The new piercing mill is also equipped with a Surface Combustion reheating furnace and a Surface Combustion normalizing furnace.

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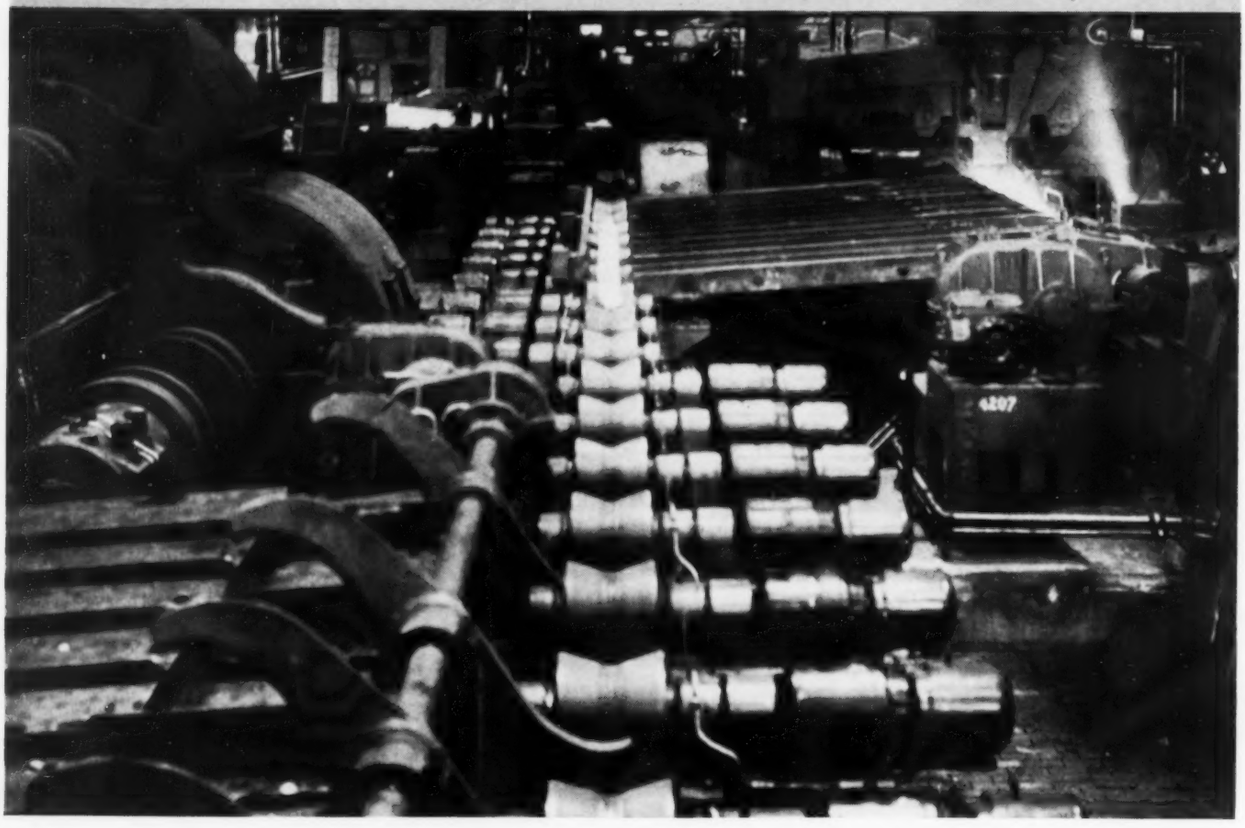
SEE OUR BOOTH No. 30
GAS EXHIBITS BUILDING
NEW YORK WORLD'S FAIR

SC

Judge Them by PAST PERFORMANCE



—and it will be Hyatts Again

In the tables at the Youngstown Sheet and Tube Company's new seamless tube mill, as illustrated, Hyatt Roller Bearings are employed. They are likewise serving in other Youngstown units—the strip mills, cars, motors, and so on.

Past dependable performance in Youngstown equipment, we like to feel, had considerable to do with the continued use of Hyatts. Repeat order after order, in mill after mill, like this makes Hyatt a dominant bearing in steel mill service.

Where and when can we serve you? Hyatt Bearings Division, General Motors Sales Corporation, Harrison, New Jersey; Detroit, Chicago, Pittsburgh and San Francisco.

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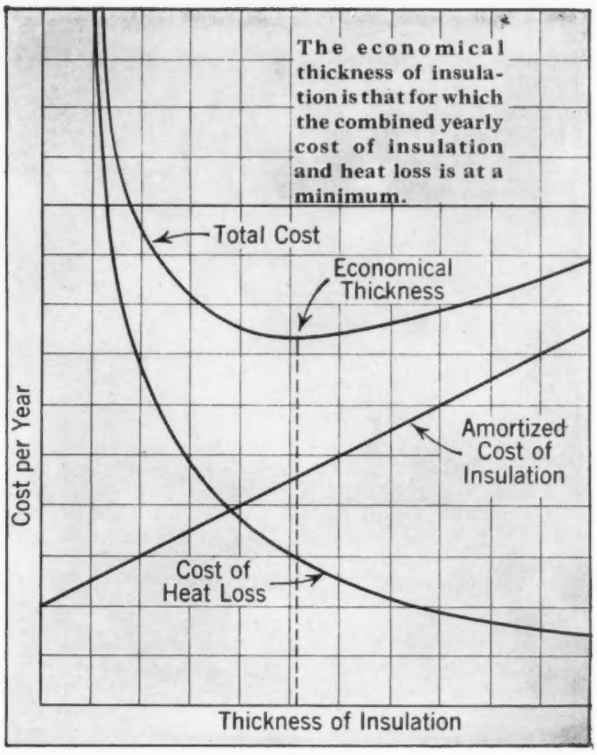
How to SAVE THE MOST MONEY with INSULATION


The economical thickness of insulation is that for which the combined yearly cost of insulation and heat loss is at a minimum.
Total Cost
Economical Thickness
Amortized Cost of Insulation
Cost of Heat Loss
Cost per Year
Thickness of Insulation

Make sure all your equipment is insulated with the *correct materials* in the *one correct thickness* that combines maximum operation efficiency with minimum heat waste

WHETHER or not your insulation is a paying investment depends entirely on the materials used and the amount applied. *Too much* will never pay an adequate return . . . *too little* results in heat losses that build up excessive fuel bills. But proper insulation, properly applied, will avoid both these costly mistakes. And a J-M Engineer will be glad to work out the most economical application.

Let him go through your plant and make a thorough study of your requirements. He'll give you the benefits of all the knowledge and data that Johns-Manville has accumulated during 81 years of research and practical experience on insulation problems. He can show you—from the complete line of J-M Insulations in brick, block and pipe-covering form—what materials are best suited for all your equipment. He can tell exactly how much insulation you can profitably use, and his recommendations will point the way to worth-while reductions in your fuel costs.

J-M Insulation Engineers have saved many individual plants thousands of dollars a year. There's a good chance they can do the same for you. For full details on J-M's free Engineering Service and on J-M Insulating Materials, simply write Johns-Manville, 22 East 40th Street, New York City.

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INDUSTRIAL INSULATIONS

For every temperature . . .
For every service condition

Reduce Your Fuel Costs in 1939

NEW TYPE MATERIAL HANDLING JACK

▲ Mechanical materials handling has been placed within the financial reach of even the smallest plant with the introduction of a new jack developed by the Yale and Towne Manufacturing Company. This new jack, known as the "Rollaway Jack" can be used in conjunction with from one to ten skid platforms. The jack is streamlined and mounted on rubber-tired wheels revolving on roller bearings set on a high carbon axle. Utilizing the narrowest wheel tread available, this jack has reduced radically the tendency of handle whip. All main engaging members are of heat-treated alloy steel. A balanced type handle, with the equalizing spring enclosed inside the tube, forces the handle upright when the platform is elevated. This is an important safety feature as the handle is prevented from falling on the ground, and becoming a dangerous obstruction to operator and passers-by.

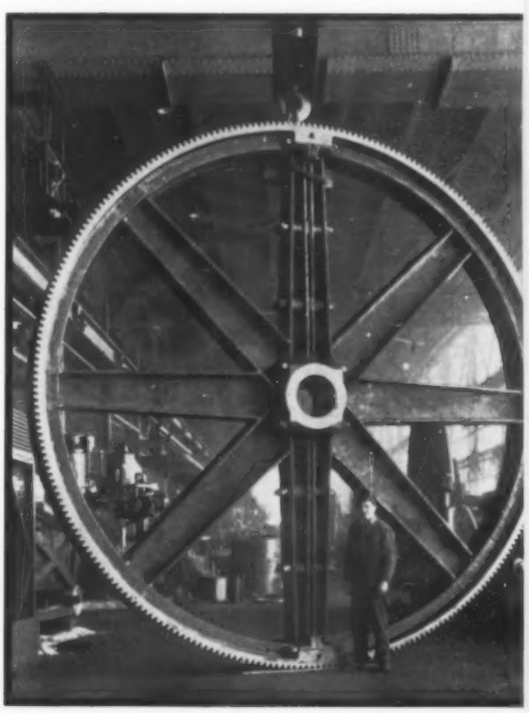
The "Rollaway Re-Nu Top" skid platform has been designed for use with the new jack. Mounted on roller bearings and set on axles of high carbon steel, it rolls with ease. A unique means of welding employs a sub-frame to tie all units into one inseparable unit. The front prong, cross-members and front legs are one unit, as are also the rear wheels and cross-members. These two units are in turn built into the sub-frame, thus made into one rigid piece that is welded and bound by the lower angles. The entire platform frame is of open hearth steel, with a heat-treated steel pin for the connecting prong.

The Rollaway jack, in conjunction with skid platforms, affords material handling facilities for a wide range of applications.

HERRINGBONE GEAR FOR ROLLING MILL

▲ The Farrel-Sykes continuous tooth herringbone gear, shown in the accompanying illustration, is over eighteen feet in outside diameter, with a 25-inch face. The total weight of the two steel castings from which the gear is made is 44,900 pounds. The two halves are carefully machined and bolted together with fitted bolts. The teeth are accurately generated by the Sykes process. The gear was

This large gear is over 18 feet in diameter, and will transmit 800 hp. at 360 rpm.



made by the Farrel-Birmingham Company, Inc., for driving a rolling mill. It is capable of transmitting 800 horsepower at 360 revolutions per minute. The ratio of the gear and pinion is 18.12/1, the speed of the gear is 19.85 revolutions per minute and its peripheral velocity, 1130 feet per minute.

CAST REFRACTORIES FOR SPECIAL SHAPES

▲ As a result of its recent development work on castable refractories, Johns-Manville announces a new light weight "Firecrete" for making special refractory shapes, for replacing difficult brick construction, for lining furnace doors, and for making small monolithic linings. The new product is suitable for working temperatures up to 2200 degrees F.

Accepted laboratory and service tests have shown that this latest development possesses an exceptionally low heat storage capacity. This is of especial importance in intermittently operated furnaces, since appreciable quantities of heat are wasted in heating heavy fire brick and then allowing the furnace to cool. Light weight "Firecrete" has been shown to be four times as effective as fire brick in retarding heat, while having only half its weight. The resistance to spalling

Special shapes may be formed by mixing Firecrete with water, casting it in a form, and drying for 24 hours.

is such that it will withstand direct exposure to flame temperatures.

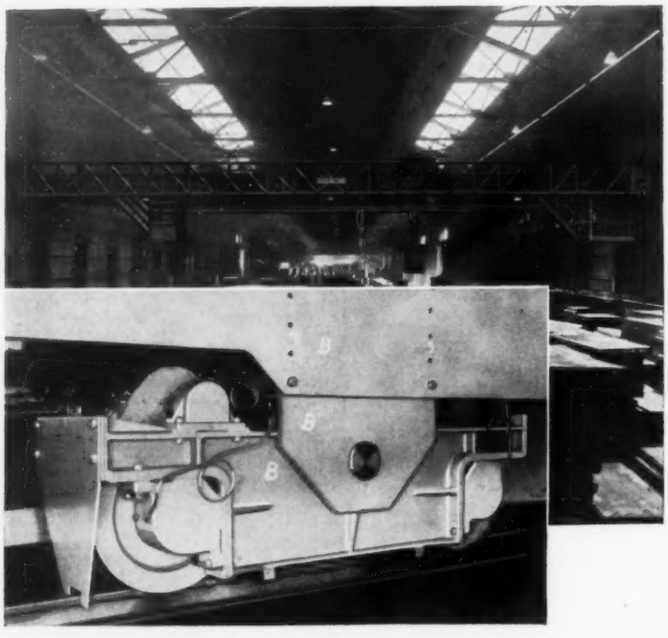
Sixty-five pounds of the material are required per cubic foot of finished construction. It can be used to form any required refractory shape. This is accomplished within a short period of time simply by mixing the material with water and casting it into a form. Twenty-four hours later the shape is ready to be placed in service.

REPUBLIC ADDS NEW STAINLESS EQUIPMENT

▲ Extensive installation of new equipment and re-arrangement of present equipment in the Warren and Massillon plants of Republic Steel Corporation will result in greatly increased stainless capacity at Massillon, Ohio, and cold rolled carbon steel strip capacity at Warren, Ohio.

CLEVELAND CRANES

Steel Mill Cranes of Steel Mill Steel



● The all welded type of crane has found increasing favor in the large steel mills of this country—doing twenty-four hour duty under the most gruelling service.

● Insert photo—Equalizer truck assembled in position showing oil tight gear case and connections from one shot lubricating system.

ALSO BUILDERS OF CLEVELAND TRAMRAIL MATERIALS HANDLING EQUIPMENT

CLEVELAND CRANES

THE CLEVELAND CRANE & ENGINEERING CO.

1131 Depot St.
WICKLIFFE, OHIO.

NEW YORK DETROIT PITTSBURGH CHICAGO

Work on the improvements will be started immediately and will take some months to complete.

Stainless capacity, with the exception of the hot rolling operations, will be concentrated in Massillon, the hot rolling to be continued in Warren. Three annealing and pickling lines are being moved from Warren to Massillon, and three new reversing mills, a 34 inch, 4-high, a 28 inch, 4-high, together with a 2-high skin pass mill are to be installed at Massillon.

The cold rolled carbon strip capacity at Warren will be substantially increased due to the removal of stainless cold rolling to Massillon. In addition to new equipment at Massillon, it will be necessary to rebuild a part of the present structure.

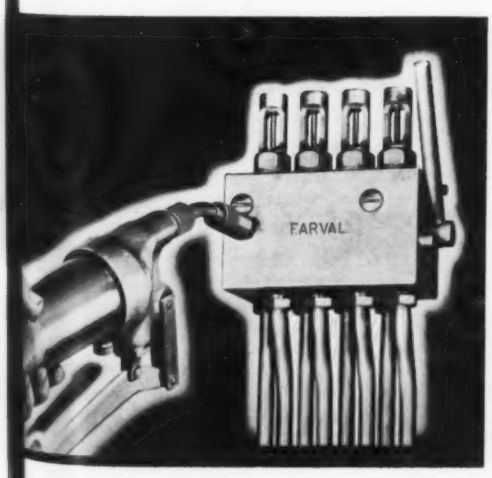
LUBRICATING SYSTEM FOR SMALL MACHINES

▲ A new system for lubricating small machines or a few bearings on larger machines from a single grease inlet has been developed by the Farval Corporation. The new unit consists of a multiple measuring valve block with a single inlet port and from two to eight lubricant outlets per block. As many valve blocks as are necessary to lubricate all bearings on a machine can be installed and connected in series.

The positive pressure lubrication of every bearing is accomplished by connecting a conventional type of hand or power grease gun to the grease nipple at the inlet port and moving the rotary valve handle. In one position lubricant pressure moves the valve pistons in one direction to deliver lubricant to one set of outlets. When the valve handle is moved to the opposite position, lubricant pressure moves the valve pistons in the opposite direction to deliver lubricant to the other set of outlets. Movement of the tell-tale indicator stem attached to each valve piston, shows the oiler that each bearing has received its measured amount of lubricant.

The amount of lubricant delivered to any pair of outlets is individually adjustable and not a bearing is missed. The new multiple measuring valves

Small lubrication applications are provided for by this multiple valve block with single inlet.



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Results in a better product because it gives a correct indication of furnace atmospheres. Built husky enough to stand the severest steel mill conditions yet sensitive enough to register accurately in increments of .0025 in. water. Employs the famous Hays Slack Leather Diaphragm—self sealing—not damaged under sudden excess pressures. Two draft valves, two pressure valves, two differential valves, or a combination of any two of these three valves may be recorded. Or a temperature recorder may be substituted for one of these valves. Send for descriptive literature. Write for detailed information to 955 Eighth Ave., Michigan City.
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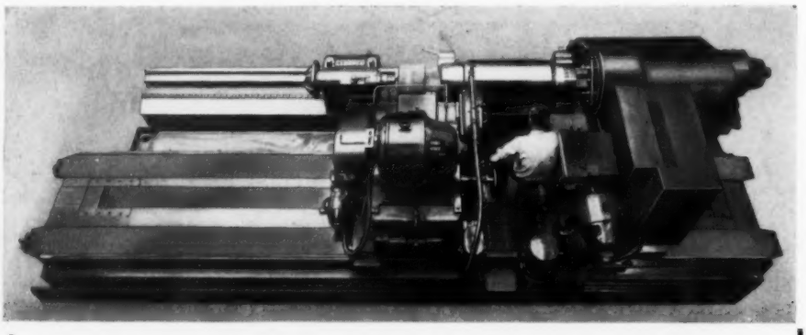
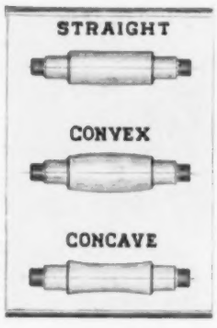
MICHIGAN CITY, INDIANA, U.S.A

contain no check valves and no springs, and are extremely simple in design and construction. Advantages claimed for the new system include: the certainty that regardless of location, no bearings will be neglected; labor saving, due to the fact that one connection serves outlets; assurance that each will receive an exact, measured amount; lubricant saving because none is wasted; increased output by properly lubricated machines; reduced costs for repair and maintenance; and prolonged life of machine equipment.

The process has been successfully applied to 60 inch and 84 inch mill rolls, various refiner rolls, mixing, crusher, washer, and tin mill rolls, hard rubber grinding rolls, and warming mill rolls.



FARREL HEAVY DUTY ROLL GRINDERS



Grind Straight, Convex or Concave Contours to Exact Symmetry and Accuracy

The quality of surface and accuracy of gauge of rolled metal strip and sheet depends upon the finish and accuracy of the rolls through which it is passed.

Farrel Heavy Duty Roll Grinders grind rolls of any material with extreme precision and with any desired finish which can be obtained with wheels at present available. They are equally capable of heavy roughing or fine finishing and produce a perfect surface free from marks of any kind. Straight, convex or concave contours are ground to exact symmetry and accuracy.

Automatic and semi-automatic features reduce dependence upon the skill of the operator to a minimum, removing the shaping and finishing of rolls from the class of craftsmanship and enabling the plant management to control roll accuracy and finish in accordance with predetermined standards.

For full information send for Bulletin No. 111

FARREL

FARREL-BIRMINGHAM COMPANY, Inc.
ANSONIA, CONN.
New York • Buffalo • Pittsburgh • Akron • Chicago • Los Angeles

BLAST FURNACE GAS SCRUBBER

▲ The Peabody Engineering Corporation, of New York, New York, announces the development of a new model scrubber for the removal of fog, dust and other particles from gas and air. It is a simplified, perfected adaptation of the scrubbing principles which characterize the company's various designs.

The new model will be known as the Peabody triple action scrubber, the separation of impurities being a three step process. Gas enters tangentially near the base of the scrubber and is there relieved of coarse particles by cyclonic action. The gas passes upward through a zone of water or scrubbing liquid, supplied by slowly rotating sprays, operating at only 10 to 15 pounds pressure. Dust particles mingle with water droplets at this stage. Continuing its travel the gas encounters a plate with coarse perforations. On passing through these, the velocity of the gas is greatly increased and with it the velocity of the dust and water droplets.

The mixture of gas, dust and droplets is shot through the plate perforations directly at square impingement baffles, constantly wet, arranged so that the stream coming through each plate perforation strikes its individual baffle at maxumum velocity. The dust particles and water droplets, on impact with the wetted baffle merge with the water surrounding the baffle. At this point, the real and final cleaning takes place. The dust particles hit the baffle with the directness of point blank rifle fire and upon doing so, are effectively and permanently captured in the scrubbing liquid.

A liquid overflow pipe, located slightly above the level of the baffles, carries off the dust laden water, which leaves at the bottom of the scrubber shell. The gas or air, freed from impurities, is deflected around the baffles and continues upward toward the outlet of the shell. Eliminator vanes, located below the outlet, entrap any droplets of water carried upward in the gas stream, thus delivering dry gas.

Great efficiency is obtained in small sized scrubbing units. An interesting comparison is provided by a scrubber 4 feet in diameter and 6

feet in height, doing the same cleaning job as a packed tower double the diameter and 130 feet high.

INDICATOR CABINET FOR EXTINGUISHER

▲ Adequate protection is afforded plants that utilize the safety features of the "Universal Indicator Cabinet" developed by the Lintern Corporation, for fire extinguishers. This cabinet provides against freezing, vandalism, and at the same time makes the fire extinguisher location visible from a distance of several hundred feet. Plants using soda, acid and foam extinguishers often find it necessary to place them in exposed locations and in unheated buildings. This cabinet eliminates the need for using a makeshift wooden box with an ordinary lamp bulb to supply heat. Each cabinet can be equipped with a dependable heating unit having a much longer life than the ordinary bulb, located directly under the extinguisher. A switch is provided for turning on the heater to give protection, by an authorized man.

In conjunction with this cabinet the new "Glowlite" descriptive signals distinguish the purpose that any particular signal may signify. Distinguishing words such as Hospital, Fire Ex., Stop, Go, Caution, Emergency, Exit, etc., are used to advantage where there are a multiplicity of signals in a particular area, or where further distinction other than color is desirable. These are available for both outside and inside applications, accommodating up to a 100-watt lamp. Any wording of ten letters or less are supplied, one inch high, perforated in a shield attached to lens assembly, complete with interior reflector for intensifying the worded signal.

This cabinet affords protection and visible marking for fire extinguishers and similar pieces of safety equipment.

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That powder-packed element is worth a million dollars—yet COSTS NO MORE!

TRICO *POWDER-PACKED* **FUSES**

The renewal element is different—it's **self-contained, powder-packed,** positively **tamper-proof** and **non-interchangeable** with ordinary "bare-links." The powder-packing **re-inforces** the fusible link—it cannot sag, stretch, lose its rated capacity, or become damaged in handling. It has a **safe** time-lag, preventing early deterioration of motor windings. Nothing has been spared to make TRICO FUSES a safe, dependable, and lasting investment.

KLIPLOK CLAMPS

Eliminate burnt fuses and clips,—unnecessary shutdowns and wasted current caused by over-heating, KLIPLOKS **correct** bad clips and **protect** new clips. There's a size for every clip. USE KLIPLOKS EVERYWHERE!

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TRICO REG. U.S. PAT. OFF. POWDER PACKED FUSES

STOP WASTED KILOWATTS AND WASTEFUL SHUTDOWNS

ITEMS OF INTEREST

Paul F. Kavanagh was appointed sales engineer for the Gordon Lubricators division of the Blaw-Knox Company, Pittsburgh, Pennsylvania. Mr. Kavanagh, who was educated at the Carnegie Institute of Technology, was formerly with the Koppers Construction Company, Pittsburgh, Pennsylvania; the Austin Company, Dallas, Texas; the Dwight P. Robinson Company, Los Angeles, California; and for the past five years represented the DeLaval Sales and Service. In the latter capacity he was engaged in engineering, sales, and installing lubricating systems in England, Russia, and in this country.

T. J. Kauffeld formerly managing director and chairman of the Inter-Continental Engineering Company, Ltd., was elected managing director and chairman of the Steelworks Design, Ltd., London, England. The new company was formed by the merger of Inter-Continental Engineering Company, Ltd., and the Alfa-Laval Company, Ltd.

William J. Breckner who for the past ten years has been in the engineering department of Morgan Engineering Company, Alliance, Ohio, was moved to the home office sales department at Alliance.

Ervin J. Sanne was appointed assistant manager of sales of the sheet and strip steel division of Inland Steel Company, Chicago, Illinois. Mr. Sanne has been district sales manager of Inland Steel Company at St. Paul, Minnesota, since 1936. Prior to that time he was associated with Joseph T. Ryerson and Son, Inc., now a subsidiary of the Inland company. He began his connection with the Ryerson company in 1917, and was active in the sales department at Chicago from 1921 to 1936.

Roland S. Higgins is now associated with the Hubbard Engineering Company, Chicago, Illinois, engaged in the practice of consulting engineering in the power plant field. Mr. Higgins, until recently was representative for the Continental Roll and Steel Foundry Company in the middle-western district. Prior to this connection with Continental Mr. Higgins was affiliated with the Smoot Engineering division of the Republic Flow Meters Company.

Ralph B. Kraft was appointed manager of the roll sales department of Lewis Foundry and Machine Division of Blaw-Knox Company. Mr. Kraft has been with the division in other capacities for some time, and has had considerable experience with the steel industry as a manufacturer's agent.

William A. Irvin has retired from the office of vice-chairman of the board of directors of the United States Steel Corporation of Delaware. Mr. Irvin will continue as a member of the board and of the finance committee, the office of vice-chairman being simultaneously abolished.

Born in Indiana, Pennsylvania, December 7, 1873, Mr. Irvin attended the local public schools, supplementing this education with a night course at the Indiana (Pennsylvania) State Normal School. In 1888 he became a telegraph operator for the Pennsylvania Railroad and advanced himself to the position of assistant freight and passenger agent. In 1894 he went to work for P. H. Laufman, Ltd., at Apollo, Pennsylvania, subsequently working his way through all operating departments and filling all departmental positions including that of superintendent, holding the latter position at the time the company was taken over by the American Sheet Steel Company in

PAUL F. KAVANAGH

T. J. KAUFFELD

RALPH B. KRAFT

W. A. IRVIN

1900. At the same time he was transferred to the company's general offices in New York where he continued in the capacity of cost clerk, and later chief of the cost department, until the company was merged with the American Sheet and Tin Plate Company in 1904. He then became chief of the sheet division of the cost department of the new company in which capacity he served until 1905, when he returned to Pittsburgh to become chief clerk of the operating department.

In 1909, he was appointed assistant to the vice-president of the operating department, and in 1925 became vice-president in charge of plant operations of the American Sheet and Tin Plate Company. In 1931, he was appointed vice-president in charge of manufacturing operations of the United States Steel Corporation in New York, and in 1932 was elected president of the same corporation. In January, 1938 he was elected to vice-chairman of the board of directors, holding that position until his recent retirement culminating forty-four years of active service.

The new Irvin Works of the Carnegie-Illinois Steel Corporation, Dravosburg, Pennsylvania, was named after William A. Irvin, in recognition of the service he rendered to the United States Steel Corporation and the steel industry.

The following appointments to the main office metallurgical staff were made by the American Steel and Wire Company.:

L. F. McGlincy was appointed division metallurgist on heating and hot rolling. He was formerly open hearth and hot mill superintendent for the company at Worcester, Massachusetts.

R. H. Barnes formerly district metallurgist in Cleveland, Ohio, becomes division metallurgist on flat rolled products and strip.

A. F. Ilacqua formerly standard practice metallurgist at Worcester, Massachusetts, is

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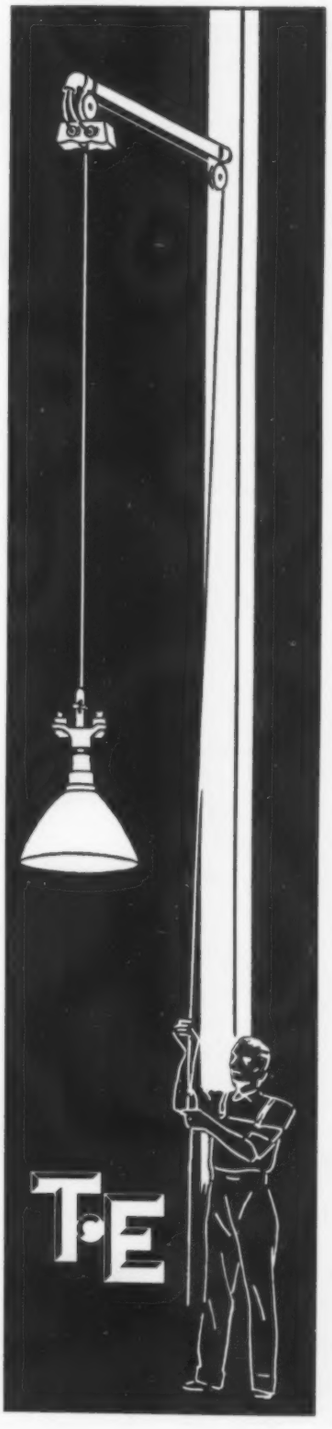

now assistant division metallurgist on high carbon products.

John F. Occasione
becomes assistant division metallurgist on coatings, whereas he formerly was in charge of similar work for the Cleveland district.

J. E. Millen
who was formerly in charge of statistical work in the company's physical laboratory in the Cleveland district, was made assistant division metallurgist on standard practice.

Leigh B. Block
has been elected vice-president of the Inland Steel Company in charge of purchases, succeeding E. J. Block who recently died. Mr. Block began his business career at the Indiana Harbor Works of the Inland Steel Company in 1924. He entered the purchasing department at that plant in 1927 and became works purchasing agent in 1928. In 1932 he was transferred to the flat rolled steel division in the sales department at the company's general offices in Chicago, Illinois, and in 1934 was appointed assistant vice-president and assistant manager of sales of that division.

R. J. Knerr
was recently appointed superintendent of the Lehigh mills, Bethlehem Steel Company, Bethlehem, Pennsylvania. Mr. Knerr replaces Arthur C. Cusick who has held this position since 1934, and who left the Bethlehem Steel Company to become general superintendent of the Crucible Steel Company of America.

L. J. Bray
who has been general foreman of the locomotive repair shop at the Bethlehem plant of the Bethlehem Steel Company, was made superintendent of maintenance of the Lehigh mills at Bethlehem, Pennsylvania.

A. W. Chenoweth
assistant superintendent of the Lehigh finishing mills, becomes superintendent of the finishing mills at the Bethlehem Steel Company's Lehigh mills at Bethlehem, Pennsylvania.

Henry I. Maurer
formerly assistant superintendent of the 35-inch and 18-inch mills at the Lehigh Division, Bethlehem Steel Company, Bethlehem, Pennsylvania, is now the superintendent of these mills. Mr. Maurer came to Bethlehem from the Steelton plant in 1924.

H. L. Gifford
is now assistant superintendent, treatment and cold drawn departments at the Lehigh mills of the Bethlehem Steel Company at Bethlehem, Pennsylvania. Mr. Gifford went to Bethlehem from the Pittsburgh plant of the Crucible Steel Company of America in 1921.

E. F. Martin
superintendent of the Grey mills at the Saucon Division of the Bethlehem Steel Company, at Bethlehem, Pennsylvania, was appointed superintendent of the Saucon plant.

C. A. McGill
formerly assistant superintendent of the shape mills at Bethlehem Steel Company, Bethlehem, Pennsylvania, is now the superintendent of these mills.

INSULATING VARNISH, too

"conforms to specifications"

Steel men need no introduction to this term. Their customers place orders for steel "that must conform to specifications". The steel they produce must meet all specifications if a uniform output is to be produced and satisfied customers are to be made.

Insulating Varnishes are "built to specifications" too. The various grades in the DOLPH Line are not accidental productions. Each one was designed to meet some particular requirement. The various changing demands of industry are constantly being watched by DOLPH Research Technicians and when a new varnish is necessary, one is developed. A recent example of this work is the specifications of DOLPH'S No. 71 CHINALAK Clear Baking Varnish for glass insulation.

Further information regarding DOLPH Products and their ability to provide dependable protection against the various corrosive conditions encountered in the steel industry will be mailed on request.

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